A STUDY OF THE WORKPLACE ENVIRONMENT WITH RESPECT TO ASPECTS OF SAFETY AND OCCUPATIONAL HEALTH IN A SUGAR PROCESSING PLANT: THE CASE FOR MUMIAS SUGAR COMPANY, KENYA.

By

FLORENCE B. LUBWAMA, B.Sc. Agric. Engineering (Makerere)

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DECLARATION

I declare that this is my original work and has not been submitted for a degree in any other University

Date: 21/1/98

Florence B. Lubwama.

This thesis has been submitted for examination with my approval as University Supervisor.

Date: 6th May 1998

Mr. D. A. Mutuli

DEDICATIONS

Dedicated to my Parents, Mr. and Mrs. E. S. Lubwama, for making me what I am in the world today and, to all the people who have played and continue to play an important role in my life.

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ABSTRACT

A STUDY OF THE WORKPLACE ENVIRONMENT WITH RESPECT TO ASPECTS OF SAFETY AND OCCUPATIONAL HEALTH IN A SUGAR PROCESSING PLANT: THE CASE FOR MUMIAS SUGAR COMPANY

By

Florence B. Lubwama
Department of Agricultural Engineering
University of Nairobi.

A study was undertaken at Mumias Sugar Company to establish the status of the workplace environment with respect to some aspects of Safety and Occupational health in a Sugar Processing Plant between December, 1996 and March, 1997.

Studies were conducted on the environmental aspect of Hot working environments in the factory and the Dust manifestation from bagasse handling. Measurements of the environmental components were done to establish the thermal balance associated with the working environment in the Process house and Boiler house. Dust samples were taken to establish the dust concentration associated with the various workplaces. In the analysis, the least significant difference criterion was used to compare the observed means of established parameters. A questionnaire survey was conducted to establish the psychological consequences of the working environment on the exposed personnel and to facilitate a quantitative access to the people's subjective judgment of their working environment.

The thermal loads in the Process house were found to be significantly different, at 5% level of significance, attributed to the poor ventilation and uncontrolled sources of thermal stress, thus implying higher thermal stress among the exposed personnel than in the boiler house where the thermal loads were not significantly different. Dust concentrations were

not significantly different, but the dust level in the bagasse store exceeded the recommended exposure limit.

The results of the study indicated a need for better ventilation, provision of thermal clothing, or limiting exposure to these uncontrolled thermal stress conditions through the introduction of new working schedules for hot working environment, while special storage designs, alternative delivery means, or the application of moisture during the disposal of bagasse, to prevent the bagassilo from becoming airborne, were found necessary.

The results of the research will form the basis of a qualitative and quantitative assessment of some of the risks involved in a sugar processing industry which is a major requirement for the planning and effecting a health and safety programme in any industry.

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LIST OF ABBREVIATIONS AND SYMBOLS

ASHRAE	-	American Society of Heating, Refridgeration, and Air-Conditioning Engineers
α	-	Level of Significance
B_{1B}	-	Boiler 1B of the new set
B_{2B}	-	Boiler 2B of the new set
C	-	Rate of heat loss by Convection
Clo unit	-	A Measure of Thermal Insulation
E	-	Rate of heat loss by Evaporation
ENT	-	Ear Nose and Throat
E_{A1B}	-	Evaporator 1B of stream A
E_{A4}	-	Evaporator 4 of stream A
E_{B2}	-	Evaporator 2 of stream B
E_{B3}	-	Evaporator 3 of steam B
ET	-	Effective Temperature
ET*	-	Corrected Effective Temperature
h_c	-	Convective heat transfer coefficient
h_r	-	Radiant heat trnsfer coefficient
ILO	-	International Labour Organization
lsd	-	Least significant difference
MAC	-	Maximum Allowable Concentration
MCE	-	Modular Comfort Envelop
MSC	-	Mumias Sugar Company
OSHA	-	Occupational Safety and Health Administration
PMV	-	Predicted Mean Vote
P_2	-	Vacuum Pan 2 - Lower Pan Floor
$P_{5/6}$	-	Between Vacuum Pan 5 and 6 - Lower Pan Floor
P_7	-	Vacuum Pan 7 - Upper Pan Floor

P_9	-	Vacuum Pan 9 - Upper Pan Floor
P_{11}	-	Vacuum Pan 11 - Upper Pan Floor
P4SR	-	Predicted 4h sweat rate
R	-	Rate of heat loss by Radiation
rc	-	Combined rate of heat loss by Radiation and Convection
RH (rh)	-	Relative Humidity
S	-	Rate of heat being stored in the body
SPSS	-	Statistical Program for Social Scientists
t_a	-	Air Temperature
t_{db}	-	Dry-Bulb Temperature
t_{or}	-	Operating Temperature
t_r	-	Mean Radiant Temperature
t_{sk}	-	Skin Temperature
$t_{\alpha/2}$	-	Student's t value at half the level of significance
t_{wb}	-	Wet-Bulb Temperature
TVL	-	Threshold Limit Value
v	-	Air velocity
W	-	Rate expended in mechanical work
WBGT	-	Wet-bulb Globe Temperature Index
WD	-	Wet Dry Index

CHAPTER 1: INTRODUCTION

Industrial safety means elimination and/or prevention of hazardous situations to the workers, the management and the whole firm. A hazardous situation is an environment that presents a potential for injury, illness, or damage to property. Safety is something difficult to understand in the industrialisation process. Very often we talk about a completely safe design, but there is no such thing. Disregard of design principles in any of the environmental factors (layout, equipment arrangement, illumination, noise, atmospheric conditions etc.) leads to unsafe conditions.

The majority of workers in developing countries are illiterate, come from a rural or agriculture background and are therefore neither trained to handle machines nor apprised of the hazards or risks involved. The urge to earn more money leads to taking unnecessary risks like removal of machine guards, which are considered to be a hindrance, or continuous overtime work without regard of the fatigue factor. Facilities for the training of workers, particularly in accident prevention, are inadequate.

Managers are rarely trained or even unaware of their role in accident prevention. Those who are trained do not do what they are supposed to because there is no stress on safety regulations. With the exception of a few enlightened employers, the attitude of provision of safe working is at most to comply with the letter of the law rather than its spirit. Non-compliance with safety regulations resulting in serious or fatal accidents at most just attracts a fine. This neither deters nor compels the employer to accord proper attention to the safety of his workers.

Safety rules and regulations are elaborate and mostly copied from developed countries, but in most cases their execution is often ineffective. There is no short-cut to the attainment of high standards of safety, nor can a number of laws and regulations bring about substantial prevention of accidents. Safety is not simply a concern of professional ethics, it is a direct legal and financial responsibility. When hazards cannot be designed-out (eliminated), warnings and protective devices must be part of the design to maximise operator control and safety. The potential hazards, the financial cost of any single loss and public awareness of the dangers require industries to devote considerable effort to reducing the risk of an accident to a very low level.

Safety measures ought not to be learnt after an occurrence of an accident. Accidents hurt, disable people and are costly, but can be avoided. Time lost, the medical attention required, hired (substituted) labour, damage to property and intangible losses incurred when safety fails, all imply money lost. Therefore, safety effort is emotionally satisfying and economically logical. Workers must not believe that accidents happen to someone else and management must believe that accident prevention is worth the cost.

In general, there are two basic causes of accidents: unsafe acts by workers; and unsafe working conditions. Accidents attributable to physical and mechanical sources with the work environment are caused by unsafe conditions. It is not uncommon to notice inadequate or inefficient lighting, extremely hot or cold working environment, release of undesirable material, and inadequate ventilation. These were some of the unsafe working conditions that were addressed in this research, with particular emphasis on the hot working environments and release of dust in agro-industries. According to the risk-accident-damage sequence, action for accident includes: prevention of accidents, through action on sources of potential risk and triggering causes of accidents; and protection of dangerous situations and expected accidents.

Mumias Sugar Company (MSC) is one of the few agro-industries in Kenya where workers' health and safety has received considerable attention. Owing to the ongoing work in the factory in readiness for the new diffuser project, the management has taken serious consideration of safety measures to avoid industrial accidents. The management further intends to incorporate a health and safety department to reinforce these measures.

1.1 Background

Mumias Sugar Company, Kenya's most successful sugar producing industry, is situated in Kakamega district of Western province of Kenya. The company has been operational since

1973 with the Government of Kenya holding 71% of the shares. The original factory sugar production capacity was at 45,000 t/y but steady expansion and growth over the past years have seen the capacity to a current level of 200,000 - 213,000 t/y [Makatiani and Toywa, 1994].

A major rationalisation project has been under way for the past two years. The main element in this project is the changing of milling technology and replacing it with a Diffuser tank about 9m long. Extraction by a diffuser is a relatively new technology, widely used in many countries, but especially South Africa, to increase sucrose extraction from the cane. The overall extraction achievable by diffusion is generally higher than that from a milling tandem largely because it is impossible to apply higher rates of imbibition.

But, whereas it is necessary to strive hard to industrialise in order to promote economic growth, it has been realised that industrialisation can be a 'double edged sword'; one side promoting economic uplift and the other side causing disablement or even death of workers. This has been more so in developing countries which apply tremendous pressure to increase production disregarding the norms of hours of work, training of workers, guarding of machines and provision of personal protective equipment. In Mumias Sugar Company, like in many factories in developing countries, the unsafe acts of the workers and the limited knowledge of the effects attributed to industrial safety measures still render the workplaces hazardous to personnel.

Njau (1990) carried out a some work in respect to some aspects of occupational health and safety in agricultural and industrial working environments. In his approach to the thermal environment, Njau set out to establish Heat exposure levels by evaluating the predicted mean vote (PMV) as one of the indices for thermal comfort where PMV is a function of thermal environment variable as defined by Fanger in 1970. He successfully defined the work environment along these terms in the industries he covered. However, Njau's work did not cover workplace environments in a sugar plant.

1.2 Justification

In order to plan and put into effect a health and safety programme in a sugar industry, the first requirement is a qualitative and quantitative assessment of the risks involved in each industry in view of the fact that there are variations from plant to plant [Luigi, 1989]. The present position in developing countries is such that there are industries with very high standards of safety existing side by side with others that take virtually no measures.

The recognition, monitoring and evaluation of the factors arising from the working environment which cause sickness, impaired health or significant discomfort and inefficiency should constitute the objective of any study of health and safety. For MSC, which is planing to put into effect a health and safety programme, evaluation of these factors therefore was important.

The working environment is the crucial area of occupational risks, and workers' education in occupational health and safety should be focused on it with a view of obtaining the necessary improvement. An understanding of the physiological principles is essential for an engineer in establishing designs effective for safe working conditions. Not only may a hazardous working environment be a direct cause of occupational accidents and diseases, but the workers' dissatisfaction with working conditions which are not in line with their current cultural and social level may also be at the root of the decline in production quality and quantity, excessive labour turnover and increased absenteeism.

1.3 Objectives

So, in view of above, a research project was undertaken at MSC to investigate some of the factors arising from the working environment with the overall objective of establishing the present status of the workplace environment with respect to some aspects of occupational health and safety in a sugar processing industry. The following specific objectives were addressed:

1. To establish the magnitudes of the environmental components and dust levels in workplaces and, compare the established magnitudes with recommended values.

2. To compile the thermal environment balance associated with the working environment under study (as a measure of working comfort or discomfort).
3. To establish the subjective responses from involved personnel in relation to the investigated aspects.
4. Recommend ways of controlling the adverse effects.

1.4 Scope of the study

This study covered essentially the environmental aspects of hot working environments along the sugar process line and dust manifestation from bagasse handling. The focus of this research was on the working environments in the Process house, Boiler house and the Bagasse store. Environmental components were measured in the Process house and Boiler house and the data was used to compute the thermal balance associated with these workplaces, and dust samples were taken to establish the dust concentration associated with the various workplaces around the bagasse store. The psychological consequences of the working environment on the exposed personnel were established using a questionnaire.

CHAPTER 2: LITERATURE REVIEW

2.1 Occupational health and Safety aspects

It has taken a long time for the full extent of the interdependence between working conditions and productivity to be fully recognized. The first move in this direction came when people began to realize that occupational accidents had economic as well as physical consequences, although at first only their direct costs (medical care and compensation) were perceived. Finally it has been realized that the indirect costs of having poor working conditions are usually far higher than the direct costs [Grandjean, 1982].

Life and all human activities are threatened by a number of potential risks, but it is impossible for everyone to think at all times of the damage and be aware of risk sources. A general state of safety cannot be reached by individual interventions only. There is little evidence of efforts by individual employers to prevent accidents at work; most of the information available relates to measures taken at the national or sometimes regional level by industry or public authorities. This has for many years sustained the belief that the major contribution towards the prevention of occupation accidents has to be made by governments. But accidents occur at individual workplaces and control measures must therefore be initiated at this level by the employer, managers and workers directly concerned if they are to have their full impact.

A study on health and safety conducted by the Trade Union Congress in India in 121 establishments showed that hazardous conditions existed in 84% of those surveyed. Serious accidents or fatalities had occurred in 67%. Only 8 establishments had made safety changes, another 45 took action after an accident had occurred and the remaining carried on as before [Luigi, 1989]. One estimate mentions that about 70% of factories in developing countries have obsolete machinery, with inadequate guards. Appropriate guards cannot be procured either because no one manufactures them any more or of lack of funds. The machinery used is often imported from developed countries who design them for their own workers and modes of operation (e.g. by remote control, different thermal environment in which they are operated) and, their manual operation or by workers whose body built is considerably different often creates unsafe conditions. Personal protective equipment is rarely provided and where it is, it is often unsuitable for the prevailing conditions of heat and humidity.

Occupational health and safety in Kenya, like in many other developing countries, has received little attention and comes low on the list of national priorities. A report by Gitonga (1987) says that because there are more serious problems such as communicable diseases and explosive population growth, decision makers fail to understand why any priority should be given to occupational health and safety. It is very difficult to give a clear picture of industrial accidents in Kenya. The reasons for this include the financial problem facing the Directorate of Occupational Health and Safety Services; the negligence of both employers and employees in reporting accidents; and the small number of occupational health and safety officers.

However, it has been generally noted that the working conditions in Kenya's industrial areas are pathetic. The zones are full of claims about oppression by unscrupulous entrepreneurs, poor enumeration and lack of safety. The problem lies with firms which are seizing on the unemployment problem to oppress the less-skilled and on the absence of a structure to protect workers. Multi-national profit seeking merchants now dump permanent workers for casuals, who are regarded as cheap and are not unionized. They also need not be insured. Lack of an equipped institution to follow up cases of industrial safety is absent and, the Labour Act is not strict enough. The fines of those found guilty of flouting industrial laws are lenient [Daily Nation, 1996].

In developing countries, the widespread lack of statistical data on industrial injuries and on absenteeism has made the study of working conditions impossible. Workers have taken working conditions to be a secondary consideration, to be placed after the employment itself and the wages that accompany it. However, if the waste of human and material resources, and the social-political tension are to be avoided, great attention must be devoted to working conditions. In certain developing countries it has been found that productivity can be improved merely by improving the conditions under which people work. Safety realization requires a Multi-level and Multi-disciplinary approach, and its undertaking has an important social role to play in addition to its technical and economic function. It is therefore the duty of anyone who has authority over other persons and is responsible for their safety.

2.2 Occupational health and safety legislation in Kenya

The enactment in 1951 of the Factories Act, Cap 514 of the Laws of Kenya, meant the introduction of occupation health and safety legislation in Kenya. The Act was based to a large extent on the British Factories Act of 1937. The need to enact such a law was apparent because of the high number of occupational accidents that were taking place in Kenyan workplaces at that time [Muchiri, 1992]. Since then the Factory Act has been revised several times in order to extend its coverage and improve its administration. The last such amendment was carried out in 1990 and broadened the scope of the Act to cover other places of work as defined in the Act.

Basically, the Act is confined to general principles thus making it fairly flexible and enabling the Minister of Labour to set rules and regulations without the need for frequent amendments. The Act is administered by the Director of Occupational Health and Safety Services. To enforce the Act the government is empowered to appoint occupational health and safety officers and other officers as may be needed. The officers are empowered to enter any factory, by day or night, to carry out an inspection. The officers also have the power to prosecute anyone who contravenes the provisions of the Act or rules thereunder, regardless of whether such a person is an employer or employee.

The Act is elaborate and placed in almost all the working places, with rules governing the safety and health of workers. Safety gears (ear muffs, goggles, nose protectors, overalls) are mandatory in all workplaces that present hazardous situation to the workers, but in most cases the unsafe acts of workers fail the system. Cases have also been noted where proper protective devices, especially thermal protective clothes, have been not been provided by the management.

2.3 Raw Sugar manufacturing processes

The various stages in the processing of sugarcane, from the point where it reaches the mills up to the final product and by-product, involves the harvesting of cane, collecting, transporting and processing. Sugarcane is harvested when it is mature (normally 24 months), collected and transported to the factory for processing. At the factory gate it is weighed for accounting purposes and cane payment and also for production purposes.

Once at the cane yard, it is fed into the feed tables, passed through preparation equipment (knives) for easy sugar juice extraction. The first set of knives level the tangled cane and the second set of knives complete the preparation. In the sugar mill, the juice is extracted by crushing the cane in a series of roller mills under pressure, the cane proceeding from one mill to the next on slightly inclined, slatted intermediate carriers for the conventional milling process.

When using a diffuser technology process, cane preparation must be more thorough to help achieve higher extraction. The prepared cane is feed into the diffuser where it is dragged slowly over a series of perforated screens by conveying chains. The juice is washed out of the broken cells in the prepared cane as it moves through the diffuser by a series of juice applications, each successfully more dilute, and finally by a water application. Juices are collected by trays beneath the perforated bottom and pumped forward to the preceding compartment.

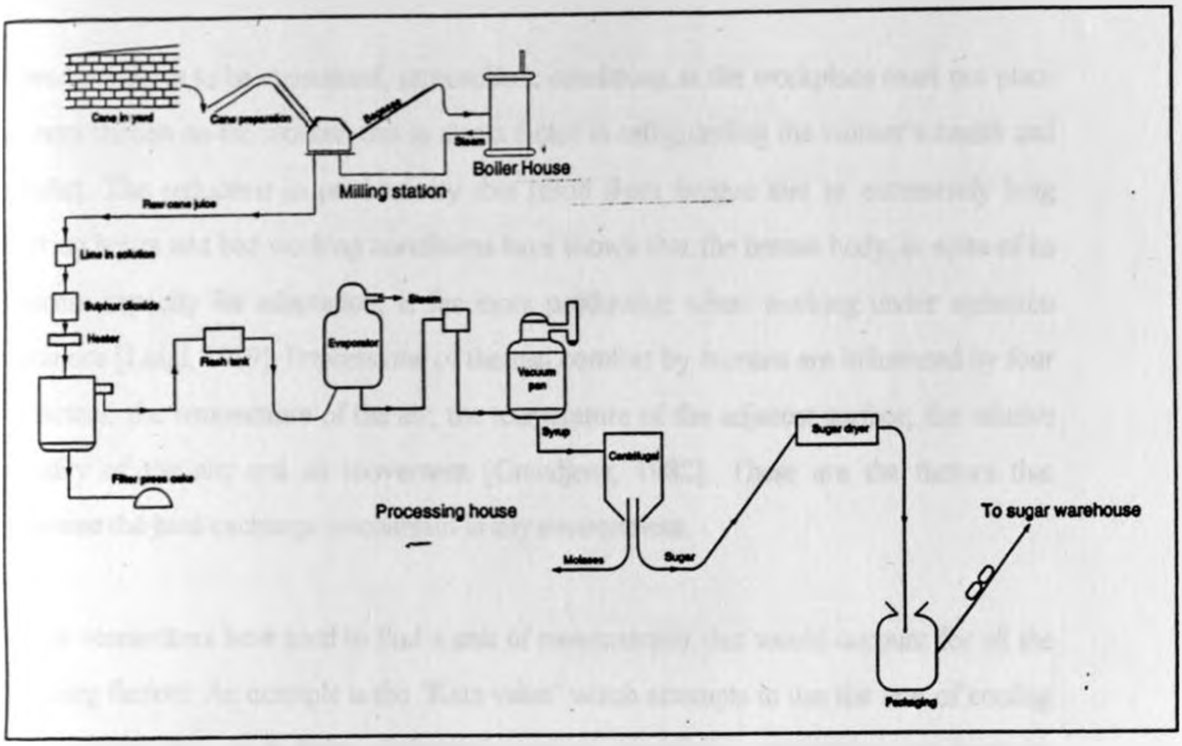
From either of the methods, the extracted sugar laden juice is pumped separately, leaving a refuse called bagasse. The juice received into the process house contains saccharose, glucose, laevulose, organic salts and acids in solution, and is mixed with bagasse fiber, grit, clay, colouring matter, albumen and pectin in suspension. Because of the albumen and the pectin, the juice cannot be filtered cold: heat and chemical agents are required to eliminate the impurities and to obtain saccharose.

The juice from the mills is acidic and turbid. The clarification process, designed to remove both soluble and insoluble impurities, universally employs lime and heat as the clarifying agents. Clarification by heat is the oldest and in many ways the most effective means of purifying the juice. The juice is heated to a temperature of 70°C and then lime based precipitants are added. Liming of the juice is done to correct the juice acidity and to prevent the reversion of sucrose. This lime and heat treatment forms a heavy precipitate of complex composition, part lighter and part heavier than the juice, which contains insoluble salts, coagulated albumin, and varying proportions of the fats, wax, and gums.

The lime also combines with phosphates in the juice to form a woolly-looking mass of lime phosphate which holds the suspended dirt. This is deposited as mud in the clarifiers. Secondary heating to a temperature of 110°C completes the clarification process. The juice then flows to the flash tank where the super heat is vented off to the atmosphere. The juice at a lower temperature (less than 100°C) is distributed to the clarifers where a polyelectrolyte (Magna floc) is added to enmesh the flocs in the solution forming bigger flocs before depositing to the lower compartment of the vessels.

Before the juice is pumped to the evaporators, it is preheated to a temperature of 110°C since the temperature had dropped in the flash tank. In the evaporators, the juice is evaporated to form a syrup. The treated syrup is concentrated in the vacuum pans and precipitates in the form of greyish crystals. Since high temperatures are used or produced in the evaporators and vacuum pans, the fumes and steam given off are troublesome and sometimes toxic.

The concentrated juice, or massecuite, contains 45% of water. Centrifugal treatment produces granulated sugar of a greyish hue and molasses. The molasses are expelled through holes in a perforated screen as the crystals remain in the basket. The rate of removal of the molasses directly depends on the centrifugal force as a result of the rotational speed of the basket. After the centrifugal process, the granulated sugar is discharged into a scoll, and with the help of a screw conveyor, it is discharged into an elevator which sends the sugar to the screen via a drier before being emptied into the sugar bins.



Source: Olale-Awilly, 1996

Figure 2.1: Raw Sugar Manufacturing Processes (Schematic)

The residue from the milling or diffusing of the cane, the bagasse, is conveyed to the boilers for use as fuel for high pressure steam generation. Steam is used in the turbines which drive the mills through reduction gear units, and the exhaust steam from the prime movers is used for boiling juice to syrup in the evaporators and vacuum pans. Even with a normal fibre content and a well-balanced and well-designed factory, an excess of bagasse still remains because of electrification and at times due to other means of fuel economy. The handling of this excess presents a problem because of the bulk of the material. The dust from this bagasse fibre, with residue from ovens, can irritate the respiratory tract and cause health hazards. Figure 2.1 shows the sugarcane processing stages for the conventional mill tandem.

2.4 Environmental Design of the Workplace

If productivity is to be maintained, atmospheric conditions at the workplace must not place an extra burden on the worker; this is also a factor in safeguarding the worker's health and comfort. The reduction in productivity that result from fatigue due to excessively long working hours and bad working conditions have shown that the human body, in spite of its immense capacity for adaptation, is far more productive when working under optimum conditions [Luigi, 1989]. Impressions of thermal comfort by humans are influenced by four (4) factors: the temperature of the air; the temperature of the adjacent surface; the relative humidity of the air; and air movement [Grandjean, 1982]. These are the factors that determine the heat exchange mechanism in any environment.

Several researchers have tried to find a unit of measurement that would account for all the foregoing factors. An example is the 'Kata value' which attempts to use the rate of cooling of an artificial body as an index of thermal comfort, though this method has not been put into practice [Grandjean, 1982]. Therefore, researchers have come to rely more on the subjective impressions of test persons as a measure of the degree of thermal comfort. In all cases it is essential to consider thermal burden in relation to the energy expenditure required by the worker, since the body has to deal with a combination of stress factors.

The environmental conditions which produce feelings of lassitude (tiredness of the mind), mental irritability, reduced mental and physical efficiency or acute illness and collapse will vary with individual characteristics of the exposed person. As the temperature changes below or above the optimum for comfort, problems arise of a subjective nature and then physical problems which impair the efficiency of the worker. Extreme temperatures however can reduce work efficiency. Thermal shock and skin damage are the obvious effects of extreme temperatures. Table 2.1 shows some of the effects that have been noted on the whole.

Acclimatization, a series of physiological adjustments, occurs when an individual is habitually exposed to extreme thermal conditions, hot or cold. Although there is some question about the time required to become fully acclimatized, it is evident that much acclimatization to heat occurs within 4 to 7 days, and reasonably complete acclimatization occurs usually in 12 to 14 successive days of heat exposure. Quite a bit of acclimatization to cold occurs within a week of exposure, but full acclimatization may take months or even years [Sanders and McComic, 1987]. Even complete acclimatization does not fully protect an individual from extreme heat or cold, although acclimatized individuals can tolerate extremes better than those who are not acclimatized.

Table 2.1: Effects of temperature exposure

Temperature	Effects
Below 10°C and above 30°C	- Hand strength decreases. - Touch sensitivity decreases at low temperature.
48.9°C	- Tolerable for about 1 hr, but is far above physical or mental activity range.
29.4°C	- Mental activities slow down - slow response, error occurs.
23.9°C	- Physical fatigue begins as the temperature increases.
18.3°C	- Optimum condition.
10°C	- Physical stiffness of extremities begins as temperature increases.

Source: Clark, 1987

Based on the atmospheric (climatic) criterion, three categories of workplaces can be identified: Hot work, Cold work and Wet workplaces. Hot workplaces are characterized by the use of high temperatures which in most cases are way beyond tolerable limits for thermal comfort. Sugar industries are such examples of Hot working environments. Cold working environments on the other hand, are characterized by the use of low temperatures. Such working conditions can be sighted in refrigeration premises. In Wet working environments the process requires a high level of atmospheric humidity as in textile industries, or produces large quantities of steam as in canning industries.

Although work in low temperatures is more common now than it was some years back, practitioners in Occupational medicine are still less familiar with it than work in high temperatures [Grandjean, 1982]. Human performance in extreme cold depends ultimately on the maintenance of thermal balance. However, a number of complicated interrelations between the physiological, performance, and the sensory aspects of the effects of cold exposure exist. The person's ability to work in the cold is dependent on the personal integrity of the brain and limbs. The classical signs of exposure of the brain to cold conditions are first confusion then in-coordination. Cooling the limbs, on the other hand, results in numbing and clumsiness.

High levels of humidity (wet work) are poorly tolerated at high temperatures, in particular when there is a significant workload [Grandjean, 1982]. It is considered that the temperature as indicated by the wet-bulb thermometer at the workplace should not exceed 21°C (70°F). It is extremely difficult to keep within this limit in hot countries, in circumstances where the process requires a high level of atmospheric humidity, or produces large quantities of steam. Excessive humidity is also poorly tolerated in combination with low temperatures; the relative humidity should be kept within a range of 40% to 70%. However, only effects of Hot working environments were treated in detail.

2.4.1 Work environment standards

Essentially, work environment standards refer to occupational health and safety standards. In reality most of the effort in this respect has been focused on developing health standards while very little has been done in the field of safety. A report by Muchiri (1993) says that this has been due primarily to the scarcity of investigative information to provide support to the criteria for safety standards; the rapidly growing technology; and the unavailability of sufficient engineers in the field.

The exposure limits aim at protecting the ordinary workers against ill-health and discomfort. The criteria and methods used for determining the limits and the legal status vary from country to country. In practice, they vary between the stringent concept of maximum allowable values which should not produce any biological or functional changes whatsoever, and the more elastic approach of Threshold Limit Values (TLV) which make allowances for reversible clinical changes. In both cases, the standards are established on the basis of an 8-hr shift exposure for moderate and normal climate conditions.

2.4.2 Environmental components and their measurement

The important components of the thermal environment are: air temperature, radiant temperature, humidity, and air movement or wind.

2.4.2.1 Air temperature

A measurement of air temperature, sometimes referred to as shade temperature or dry-bulb temperature (t_{db}), is the obvious starting point for thermal environment assessments. The air temperature is the simplest practical index of cold or warmth under ordinary room conditions. For average humidity (40-60%), t_{db} has significant meaning in judging comfort especially towards the cold. In the heat, when humidity also affects the efficiency of the body's temperature regulation by sweating, the significance of t_{db} is limited.

It is important that techniques for measuring air temperature exclude possible effects of radiant heating or cooling on the sensor. A common example of error from this source is when a mercury thermometer is used for measuring air temperature and readings erroneously high due to direct radiant heating of the thermometer. Traditionally air temperatures are measured with mercury-in-glass thermometers shielded from radiation by being enclosed in some form of screen. It is also common to measure air temperature in conjunction with wet-bulb temperature using an instrument known as a psychrometer. Because mercury freezes at -50^{0}C, where extremely low temperatures are anticipated it is advisable to use an alcohol thermometer. A disadvantage of mercury or alcohol thermometers, apart from their fragility, is that they do not lend themselves to automatic measurement or recording.

It has therefore become commonplace to use various electrical temperature sensors such as thermocouples or thermistors. The latter are now widely available and consist of small beads of semiconductor material the electrical resistance of which varies with temperature in a predictable manner. In conjunction with appropriate electronic circuitry they can be used to measure temperature over a very wide range and with accuracies up to +/- 0.05 (1%) of the range.

2.4.2.2 Radiant temperature

The radiant temperature is defined as the uniform surface temperature of an imaginary black enclosure with which a man (also referred to as a black body) exchanges the same heat by radiation as in the actual environment. Radiant heat is given out by all bodies at all temperatures. Radiant exchange between two bodies varies as the difference in the fourth power of the absolute temperature of their surfaces and is influenced by a characteristic known as emmisivity. Matt black surfaces emit and absorb radiant heat in great quantities than white surfaces.

Because of its effect on human comfort, it is sometimes desirable to measure the radiant exchange between a person and his/her surrounding. The radiant environment of a space is usually expressed in terms of its mean radiant temperature. The mean radiant temperature of the surrounding can be calculated with reasonable accuracy from measured surface temperatures and corresponding angle factors between the source and the individual exposed. However, this is a complicated procedure.

A much simpler technique is to measure the globe temperature, t_r, using a black globe thermometer. In its original form this consists of a hollow copper sphere, 150 mm in diameter and painted matt black. The sphere has a thermometer, either mercury-in-glass or a thermistor, placed at its center. Because of the inconvenience of the traditional globe thermometer, there has been a tendency in recent times to use smaller globe thermometers with a diameter of 50 mm. Mean radiant temperature may be calculated from globe temperature, air temperature and air movement using the following equation [Ashton and Gill, 1992]:

$$t_{r(av)} = t_r + kv^{0.5}(t_r - t_a) \quad (2.1)$$

where: k = 2.2 for t in ^{0}C, v in m/s air movement.

t_r is for a 150 mm diameter globe.

If a smaller globe is used then the constant k in the above equation should be substituted by k_d which may be calculated from:

$$k_d = k(0.15/d)^{0.4} \quad (2.2)$$

where d is the diameter in meters of the globe [Ashton and Gill, 1992].

In occupational health practice it is not always necessary to go to the complication of measuring mean radiant temperatures because the measurements of globe temperature may be used directly in the range of heat stress indices for predicting and controlling thermal stress.

2.4.2.3 Humidity

Humidity is the concentration of water vapour in the air and is usually expressed as relative humidity. Relative humidity is the ratio of the actual amount of water vapour in the air to the amount that would be present if the air were saturated at the same temperature - expressed as a percentage. Occasionally humidity is expressed in absolute terms as mass per unit mass of air (kg/kg) or as a partial pressure (mm of mercury (mmHg) or kPa). Relative humidity does not give a good impression the amount of water vapour in the air because its value also depends on temperature. An advantage of expressing humidity as a partial pressure is that it gives an immediate indication as to the likely effect on sweat evaporation.

Expressing humidity in terms of Relative humidity also has the same advantage. Higher relative humidity means slow sweat evaporation rate.

Classically, humidity is measured by measuring the wet-bulb depression. If the bulb of a thermometer is covered with a wick and kept wet with distilled water placed in an air stream, the evaporation of the water cools the thermometer which therefore reads below the dry-bulb thermometer in the same situation. These measurements are usually obtained by using an instrument known as a psychrometer which includes both the dry-bulb and wet-bulb sensors. Air flow over the thermometers is induced either by physically swinging them through the air, as in a whirling hygrometer, or by mounting the thermometers in tubes through which air is drawn by an electrically driven fan as in the Assman psychrometer. The reading of the dry-bulb and wet-bulb temperatures obtained with a psychrometer are used to enter a psychrometric chart to obtain relative humidity.

In recent years the use of psychrometers for the measurement of humidity has been less common due to the advent of a number of solid state humidity sensors. Modern "solid state" humidity sensors employ a thin film polymer capacitor element especially designed to absorb atmospheric water vapour and whose capacitance varies with ambient relative humidity. They are unsuitable for low water vapour concentrations and extremes of temperature, and must be protected from contaminations by pollutant particles especially those containing sulphur. A typical accuracy of +/- 2% relative humidity can be maintained by regular recalibration. These sensors can lend themselves conveniently to automatic data logging techniques.

2.4.2.4 Air movement

Air movement has an extremely important effect on human heat exchange both at high temperatures, where it affect convection and sweat evaporation, and at low temperatures where it produces the well-known wind-chill effect. In locations out of doors, air movement is usually unidirectional and can be measured using traditional instruments such as vane and cup anemometer. In these instruments the speed of rotation of the cups and vanes is calibrated in terms of wind speed. In industrial settings air movement is usually omnidirectional and in these circumstances the traditional vane and cup anemometers are liable to errors. Omnidirectional flow can be measured using devices based on a hot wire anemometer principle which measure the cooling effect of air flow over a heated wire.

2.5 Indices of thermal stress

There is a great many factors which contribute to the overall stress of thermal environments and the resulting thermal strain in the individuals exposed to them. The factors include the environmental components; physical properties of the body such as shape, size; physical characteristics of the clothing assembly worn; the physiological characteristics of the individual and his rate of work. Many attempts have been made to combine the above factors into a single numerical description or index, capable of predicting the likely levels of thermal stress with some degree of accuracy [Ashton and Gill, 1992]. The fruits of these endeavours may be divided into three groups.

Group 1: Indices of this group are based on an analysis of heat exchange and inevitably involve complex mathematical calculations. Examples are the heat stress index and the thermal stress index.

Group 2: Indices in this group are based empirically on physiological observations. Examples are the predicted 4h sweat rate (P4SR), the wet-bulb globe temperature index (WBGT), and the wet dry index (WD) also known as the oxford index.

Group 3: Includes indices based on immediate subjective sensations of warmth on entering an environment. The most common example is the effective temperature scale (ET) and a derivative allowing for radiant heat which is known as the corrected effective temperature (ET^*).

In practice, however, many of these indices have received minimal practical application. Notable exceptions, however, are the effective temperature scales, the wet-bulb globe temperature index, and the wind-chill index.

2.5.1 Effective temperature

This is the temperature which combines the effect of dry-bulb temperature, wet-bulb temperature, and air movement to yield equal sensation of warmth and cold. Houghton and Yaglou in 1923 were the first to investigate the relationship between temperature and humidity of the air that would result in the same effective temperature [Sanders and McComic, 1987]. There are two indices of effective temperature: the original effective temperature (ET) scale and the corrected effective temperature (ET*) scale.

The original effective temperature was intended to equate varying combinations of temperature, humidity and air movements in terms of equal sensations of warmth or cold. Although ET has been widely used, and has been a useful index, it overemphasizes the effects of humidity in cool and neutral conditions and underemphasizes the effects in warm conditions; also, it does not fully account for the air velocity in hot-humid conditions. Because of these limitations of ET, a newer index ET* was developed which was based on the effect of environmental variables on the physiological regulation of the body. Figure 2.2 shows the relationship between ET*, dry-bulb temperature, wet-bulb temperature and humidity. For the ET*, the scale is entered using the globe temperature in place of air temperature.

Since the effective temperature scale was devised on the basis of subjective sensation, it has proved inaccurate as a predictor of physiological response. It makes no allowance for work rate. Its main application, therefore, has been within the comfortable range and since in this range the effect of humidity is relatively small, several authorities have abandoned effective temperature scales in favour of the simpler operative temperature. For industrial operations involving moderate or high work rate it is recommended that the WBGT index be used.

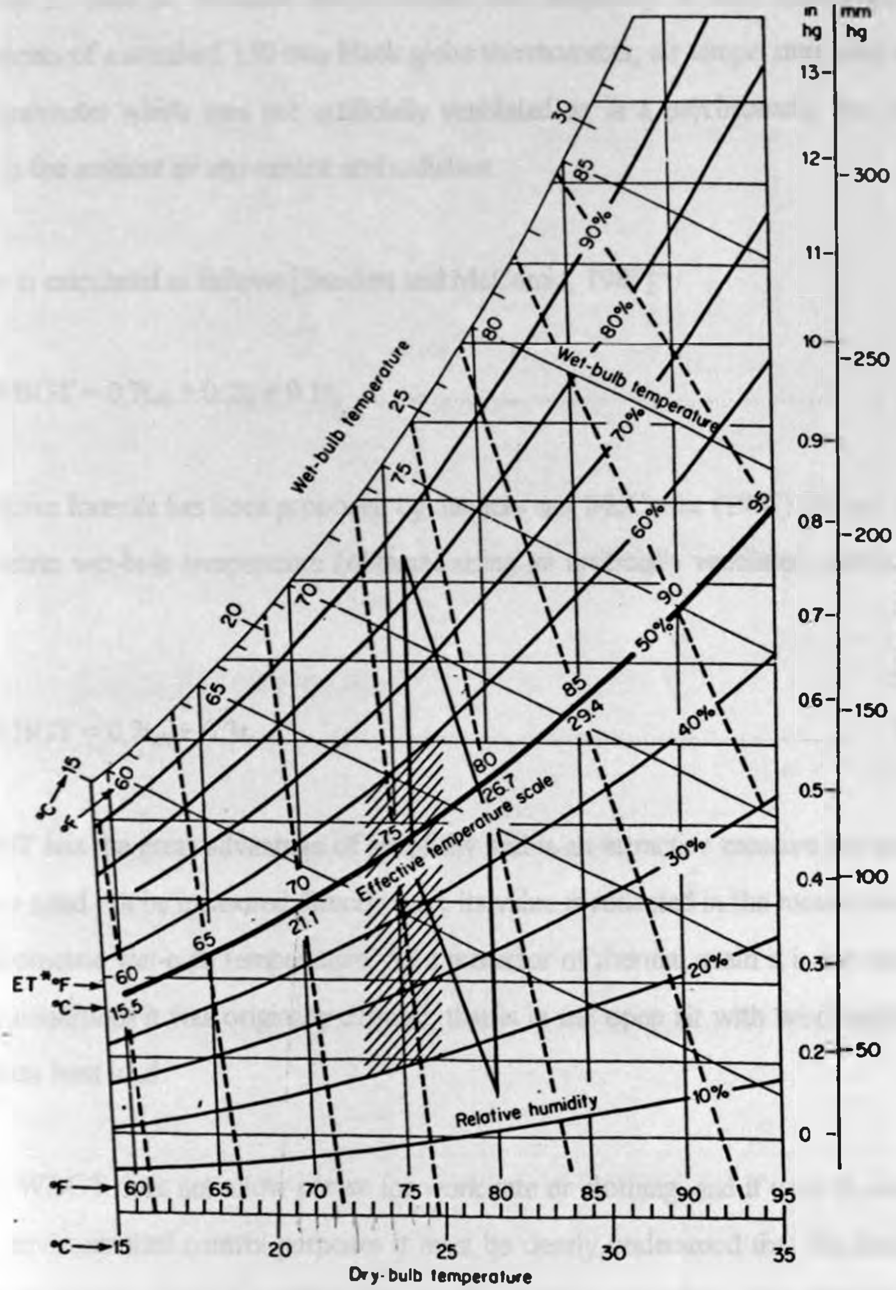


Figure 2.2: The new effective temperature (ET*) scale. The broken lines represent the ET* values. Vapour pressure is an index of humidity. Wet-bulb temperature is a measure of temperature under conditions of 100% RH, obtained with an aspirated wet-wick temperature or aspirated thermometer.

Source: ASHRAE, 1981.

2.5.2 The wet-bulb globe temperature index (WBGT)

This index is used in enclosed environments and originally it was calculated from measurements of a standard 150 mm black globe thermometer, air temperature and a wet-bulb thermometer which was not artificially ventilated as in a psychrometer but merely exposed to the ambient air movement and radiation.

The index is calculated as follows [Sanders and McComic, 1987]:

$$WBGT = 0.7t_{wb} + 0.2t_r + 0.1t_a \quad (2.3)$$

An alternative formula has been proposed by Sanders and McComic (1987) for use with a psychrometric wet-bulb temperature (obtained using an artificially ventilated wet-bulb) as follows:

$$WBGT = 0.7t_{wb} + 0.3t_r \quad (2.4)$$

The WBGT has the great advantage of simplicity and is an attractive measure because the air velocity need not be measured directly since its value is reflected in the measurement of the psychrometric wet-bulb temperature. As a predictor of thermal strain it is not accurate under the conditions it was originally devised, that is in the open air with wind movement and a radiant heat load.

However, WBGT does not allow *per se* for work rate or clothing, and if used to establish limits for environmental control purposes it must be clearly understood that the limits will be related to specific rates of working and specific clothing assemblies. The WBGT limits that would be permissible for various workloads for continuous work during a workday and for a specified rest condition as recommended by the Occupational Safety and Health Administration (OSHA) in 1974 are as shown in Figure 2.3.

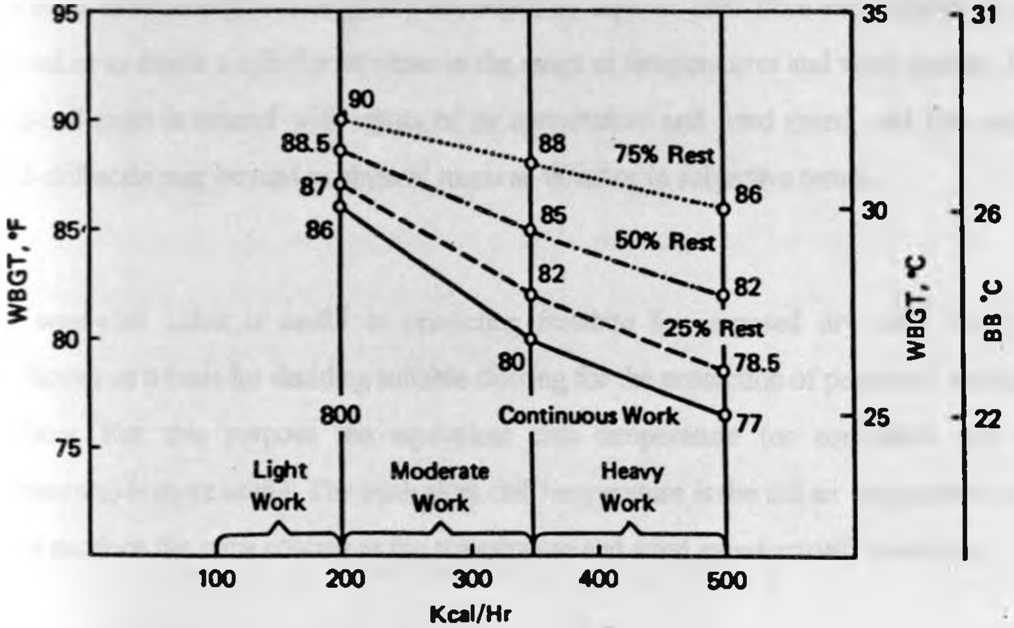


Figure 2.3: Recommended WBGT limits.

Source: ASHRAE, 1981.

The OSHA recommendations are shown in Table 2.2 with limits given for both low and high air velocities.

Table 2.2: Recommended maxium WBGT for various workloads and air velocities

Workload	Air velocities: Low: Below 1.5 m/s	Air velocities: High: 1.5 m/s
Light (200 kCal/h or below)	86°F (30.0°C)	90°F (32.2°C)
Moderate (201 to 300 kCal/h)	82°F (27.8°C)	87°F (30.6°C)
Heavy (above 300 kCal/h)	79°F (26.1°C)	84°F (28.9°C)

Source: Sanders and McComic, 1987

2.5.3 Wind-chill index and equivalent chill temperature

The index of wind-chill was originally developed by Siple in 1945 from experiments on the time taken to freeze a cylinder of water in the range of temperatures and wind speeds. The wind-mill chart is entered with inputs of air temperature and wind speed, and the center wind-chill scale may be read in physical terms as W/m^2 or in subjective terms.

The wind-chill index is useful in predicting frostbite for exposed dry skin, but less satisfactory as a basis for deciding suitable clothing for the protection of personnel working outdoors. For this purpose the equivalent chill temperature (or equivalent still air temperature) is more useful. The equivalent chill temperature is the still air temperature that would produce the same cooling as the temperature and wind speed actually measured.

2.6 Thermal comfort

It is not easy to specify precisely what conditions will be comfortable, since the feeling of comfort is influenced by many different factors and is not a tangible quantity which can be measured. It is a purely subjective feeling peculiar to each individual, and owing to the wide variations in the physical characteristics of different persons an environment which is agreeable to one may be uncomfortable to another. It is therefore usually impossible to satisfy everybody, and the best that can be achieved, particularly in rooms with a considerable number of occupants, is to provide conditions which will be agreeable to the greatest number. Although comfort cannot be measured directly, it depends to a very great extent on the provision of a suitable degree of warmth and this can be measured quantitatively, the sensation of warmth depending fundamentally on the rate and method of heat loss from the body.

ASHRAE (1981) established a thermal comfort standard that is represented in Figure 2.1 by the shaded area. In turn, Rohles in 1973 carried out an extensive study of 1600 subjects that resulted in the development of a modular comfort envelop (MCE) [Sanders and McComic, 1987]. The envelop falls between the 75 and 80°F (24 and 27°C) ET* lines, forming a diamond, which is also shown in Figure 1. The MCE applies to 'sedentary' activity with a 0.6 Clo unit clothing whereas the ASHRAE standard applies to office work with a 0.8 to 0.1 Clo unit clothing. Again, the MCE applies only to situations in which dry-bulb temperature and humidity are varied, and not to conditions of varied air movement or high activity levels or when different clothing is used.

Since the ASHRAE and MCE areas overlap, Rohles recommended the area of overlap as the 'design condition for comfort' which is specified as ET* of 76°F (24°C). Although much has been found about the sensation of thermal comfort under various conditions, there are still many gaps in the available knowledge, especially with regard to the interaction among some of the variables that influence such sensation. Working premises should be laid out and the work stations arranged in such a way as to ensure the greatest uniformity of energy expenditure amongst the persons working in a given area, in order to provide optimum climatic conditions for the majority, with allowance being made for the effect of thermal comfort on output, especially in the case of intellectual work.

2.7 Thermal regulation

The human body may be regarded as a form of heat engine whose energy is derived from the combustion of food, assisted by oxygen from the air. Only a comparatively small portion of the total energy derived from this "fuel" is expended in doing mechanical work, most of it being converted into heat. In order to maintain the correct temperature necessary for health, the body must be able to dissipate the surplus heat freely to the surroundings, and it cannot do this without discomfort unless the environmental conditions are suitable having regard to personal factors such as the degree of physical activity and the type of clothing worn.

The body has a thermal regulation system that tends to maintain the core temperature (temperature of the internal organs, i.e., interior of the brain, in the heart and in the abdominal organs) around 37°C. This characteristic is known as homeothermy and conveys important evolutionary advantages by permitting high levels of body activity which are substantially independent of body temperature over a wide range. A disadvantage, however, is that where environmental or other circumstances are such as to exceed the capacity of man's thermoregulatory process to control his body temperature (temperature of the muscles and limbs) within a degree or two of 30°C, then the consequences may be serious. Temperature regulation is brought by the control of blood flow, the secretion of sweat, and sometimes shivering. A constant core temperature is a pre-requisite for the normal functioning of the most important vital functions, and wide or prolonged variations are incompatible with human life.

In contrast to the core temperature, the temperature in the muscles, limbs, and above all in the skin shows certain variations. A comfortable person has a body temperature close to 30°C and a mean skin temperature (shell temperature) of 33°C. Skin temperatures over the trunk will usually be 3 - 4°C higher than those over the limbs. Physiological studies have shown that when the surrounding air is cool, there is a steep temperature gradient in the skin, from the inside moving outwards. In cool air, the temperature even 2 cm beneath the surface of the skin may have fallen to 35°C, whereas in warmer surroundings it may still be 35 -36°C only a few millimeters below the surface. The thermal regulation process is very much affected by the four environmental conditions already mentioned: air temperature, humidity, air flow, and the temperature of the adjacent surface.

2.8 Thermal environmental balance

The thermal environment is defined in terms of dry-bulb temperature, relative humidity, air movement and radiant thermal exchange. The "Theory of heat exchange" forms the basis of thermal environment as affecting humans. This theory states: "While the body temperature remains constant, the heat produced within the body is equal to the body heat loss: and the body heat production (M) equals the total energy production (metabolism)". In equation form [ASHRAE, 1981]:

$$S = M \pm W \pm E \pm R \pm C \quad (2.5)$$

where: S = rate of heat being stored in the body;

W = rate expended in mechanical work;

E, R, C = rate of heat loss by evaporation, radiation and convection.

When the right side of the equation is positive, average body temperature is rising; when negative, it is falling; and when zero, the body is in equilibrium. Under hot conditions, the blood flow to the skin is increased when the opportunities for heat loss to the environment are restricted. If this increase in blood flow is unable to balance the restriction in heat loss, the body enters its second stage of defence i.e., by the provision of water released from sweat glands for evaporative cooling. When evaporation ceases to be adequate, body heating occurs.

Any factor that affects the evaporation of water from the skin, also affects the regulation in the heat. Atmospheric water vapour pressure, air movement, and clothing all affect the upper limit for evaporation rate (E) above which additional sweat secretion will no longer be effective in regulating body temperature.

a) <u>Metabolism (M)</u>

In choosing optimal conditions for thermal comfort and health, knowledge of the energy expended during the course of routine physical activities is necessary, since body heat production increases in proportion to intensity of exercise. The metabolic heat produced by the body is usually measured by the rate of oxygen consumption and can either be obtained from ASHRAE tables for metabolic rates at different typical activities, or can be evaluated from equation [ASHRAE, 1981]:

$$M = [0.23(RQ) + 0.77]\,(5.8)\,(V_{O_2})\,60/A_D, \text{ in watts/m}^2 \quad (2.6)$$

where: [RQ] = the respiration quotient or the ratio V_{CO_2} to V_{O_2} inhaled; RQ may vary from 0.83 (resting) to over 1.0 (heavy exercise);

V_{O_2} = oxygen consumption in litre/min. at standard conditions (STPD) (0°C, 760 mmHg). Values of V_{O_2} for specified types of work are given in Table 2.3;

5.8 = the energy equivalent to one litre of oxygen (STPD) in watt.hr/litre, when RQ = 1;

A_D = DuBois surface area [m²].

$$= 0.202 \times 10^{-4}\, w^{0.425} h^{0.725} \qquad (2.7)$$

where: w = body weight [kg]; and h = height [m]

b) Work (W)

W is positive when accomplished by the body and when subtracted from M gives the net heat developed within the body. When W is negative, heat is added to the body system.

Light exercise, W = 300 kpm/min.

Heavy exercise, W = 1200 kpm/min.

(100 kpm/min. = 723 ft-lb./min. or 16.35 watts or 14.05 kCal/hr)

W/M = Mechanical efficiency (ε) of the human body when performing work.

Table 2.3: Classification of physical effort[a]

Work	V_{O_2}	Metabolic rate (Met units)
Very light	10	1.6
Light	10 - 20	1.6 - 3.3
Moderate	20 - 35	3.3 - 5.0
Heavy	35 - 50	5.0 - 6.7
Very heavy	50 - 65	6.7 - 8.3
Unduly heavy	65 - 85	8.3 - 10.0
Exhausting	85+	10.0+

[a] Values apply to steady state work

1 met = 58.2 W/m²; 50 kcal/h.m²; 18.4 Btu/h.ft²

Source: ASHRAE, 1981

c) Convection (C)

From ASHRAE (1981), the rate of heat loss by convection can be calculated as follows:

$$C = h_c(t_{sk} - t_a) \qquad \text{......(2.8)}$$

where: t_{sk} = mean skin temperature;

t_a = ambient air temperature;

h_c = convective heat transfer.

The convective heat exchange coefficient, h_c is not constant under all environmental conditions and depends upon the rate of air movement [ASHRAE, 1981]. It may be calculated from :

$$h_c = 8.3\ v^{0.5}\ [W/m^2\ {}^0C] \qquad \text{......(2.9)}$$

where v is the air movement in m/s

The following equation gives a reasonable first order estimation of t_{sk} [ASHRAE, 1981].

$$t_{sk} = 25.8 + 0.267\ t_o \qquad \text{......(2.10)}$$

where: $t_o = (h_r t_r + h_c t_a)/(h_r + h_c)$ ......(2.11)

h_r = radiant heat transfer coefficient

= 5.2 $W/m^2\ {}^0C$

Heat exchange by convection depends both on the temperature difference between the body and the surrounding air or water and on the rate of movement of the air.

d) Total evaporative heat loss (E)

When water evaporates from a surface, energy is absorbed during transition from the liquid to the gaseous state. This energy is termed the latent heat of vaporization and in the case of sweat evaporation a figure of 2500×10^3 J/kg is approximately correct. This figure emphasizes the extraordinary power of the human sweating mechanism as a heat loss path. The total evaporative heat loss may be measured directly from the body's rate of weight loss ($\Delta w/\Delta t$) in gm/min. as observed by a sensitive scale. E is negative in relation to M in most circumstances. When it is positive, thermal injury to the body is probable [ASHRAE, 1981].

$$E = (60\lambda/A_D)(\Delta w/\Delta t);\ [W/m^2] \qquad (2.12)$$

where: λ = heat of vaporization of water equal to 0.7 W.hr/g;

Δw = change in body weight, gm;

Δt = change in time, min.

In environments where the air temperature is the same or higher than skin temperature then sweating is the sole means available for dissipating the metabolic heat production. Under such conditions anything that limits evaporation, such as high ambient humidity or impermeable clothing, will rapidly lead to heat storage and a rise in body temperature.

e) Radiation

Exchange of heat by radiation between two surfaces depends upon the difference in the fourth powers of the absolute temperatures of the two surfaces. In practice it is often acceptable to use the first power relationship [ASHRAE, 1981] as follows:

$$R = h_r(t_{cl} - t_r) \qquad (2.13)$$

h_r depends upon the temperature of the two surfaces, the geometrical relationship between them and such characteristics of the surfaces as emittance and reflectance. Thus it may be seen that heat transfer by radiation depends principally on the temperature of the two surfaces concerned and is unaffected by air movement or the distance between the surfaces. For practical purposes the value of h_r may be taken as 5.2 W/m^2 ^{0}C.

The processes of convection, evaporative heat loss and radiation operate simultaneously, and their relative importance is determined partly by the environment and partly by the personal factors already mentioned. Heat loss by convection is reduced as the air temperature increases; evaporative heat loss is reduced as the relative humidity increases; and heat loss by radiation depends on the difference between the surface temperature of the body and the mean radiant temperature of the surroundings. If the mean radiant temperature exceeds the body temperature, the body will gain heat by radiation instead of losing it.

Where the heat loss by one method is reduced, greater quantities must be dissipated by the others to maintain the body temperature constant, and the body is provided by natural thermostatic controls capable of maintaining the body temperature substantially constant over a wide range of environmental conditions. For any given degree of activity, the different sensations of warmth produced by different environmental conditions depend more on the change in the method of heat loss than on the degree of the total quantity.

2.9 Effects of heat exposure

i) Discomfort and inefficiency

One hardly notices the internal climate of the room, as long as it is comfortable for majority of workers, but the more it deviates from a comfortable standard, the more it attracts attention. The sensation of discomfort can increase from mere annoyance to one of pain, depending on the extent to which the heat balance is disturbed. The physiological reactions of the body to various thermal conditions tend to fall into three (3) zones as shown in Figure 2.4. These include zone of cooling, zone of comfort and zone of heat regulation.

Zone of cooling: when cooling from a warm environment to a cool one, the following effects occur: routing of the blood away from the skin and more to the central part of the body; rectal temperature rises slightly but then falls; shivering and goose flesh may occur. Extreme conditions can cause hypothermia and even death.

Comfort zone: condition for which a body is in a state of approximate thermal balance.

Zone of heat regulation: the following effects occur when changing from a cool environment to a warm one: more blood is routed to the body surface resulting in higher skin temperature; rectal temperature falls; sweating may begin. Extreme temperatures can cause hyperthermia, heat stroke and even death.

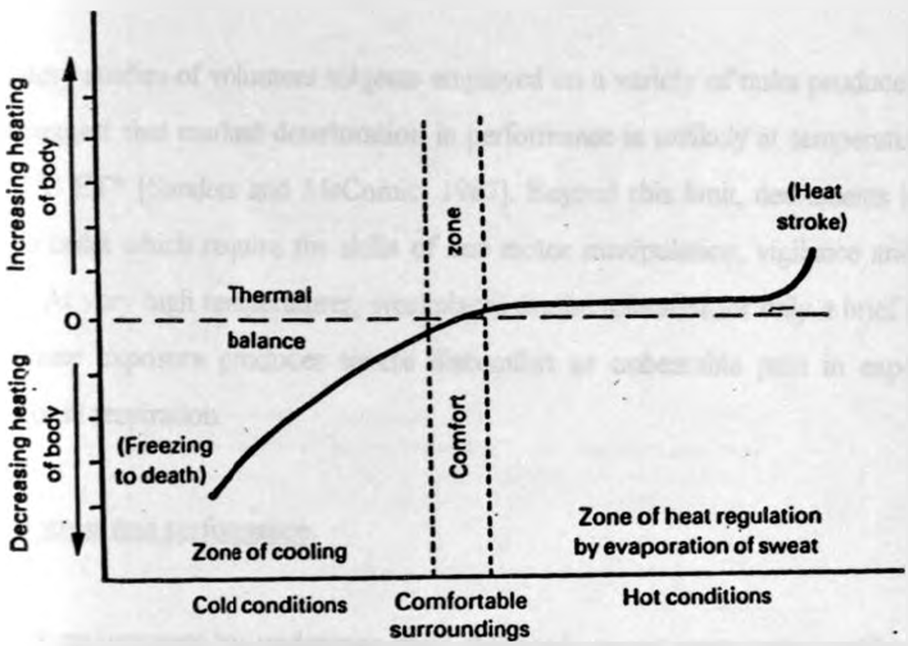


Figure 2.4: Zones of heat exchange.
Source: Grandjean, 1982.

In workplaces with extreme high temperatures, the exposed skin surface and respiratory organs of workers may be subjected to extreme discomfort, pain or tissue damage, loss of performance and increased liability to error. Limits need to be placed on the duration of exposure or on the environments to be entered by unprotected workers. In hot workplaces, radiation to the worker from all surfaces at temperatures higher than those at the surfaces of the body, produces heat gain. Physical contact with hot surfaces produces heat gains either by conduction or convection when warm air displaces that in immediate contact with the body.

Systematic studies of the effects of exposure to uncomfortably hot environments have suggested that inefficiency in the performance of tasks which require little physical effort is due to increased numbers of errors, slow work rates and lack of continuity at work which results from increased minor accidents, sickness and labour turnover. Field studies in industries have produced findings which suggest that sudden exposure to environments at a level of 23 - 25°C ET* is associated with a pronounced increase in minor accidents, absenteeism and a loss of workshop productivity.

Laboratory studies of volunteer subjects employed on a variety of tasks produced findings which suggest that marked deterioration in performance is unlikely at temperatures lower than 27°C ET* [Sanders and McComic, 1987]. Beyond this limit, decrements have been noted in tasks which require the skills of fine motor manipulation, vigilance and decision making. At very high temperatures, workplaces can be tolerated for only a brief time, if at all, because exposure produces severe discomfort or unbearable pain in exposed skin surface or in respiration.

ii) Heat stress and performance.

The work environment has undergone rapid changes in recent years: man-machine systems, while more monotonous, entail greater complications and responsibilities. Mental and physical stress too have increased. In many hot workplaces, the combination of environmental stress and physical work requires limits to be set according to the conditions which enable workers to maintain a deep body temperature at or below 38°C throughout an 8-hr shift. The relationship between heat stress and performance is complicated, the effects being related in part to the type of work activity.

In a study by Meese et al in 1984 [Sanders and McComic, 1987], factory workers were given several tasks that simulated factory work under various thermal conditions and, their performance generally deteriorated under the hottest conditions (38°C) as contrasted with temperatures of 32°C and below. Individual differences in heat tolerance levels, the type of work, clothing worn, air circulation, and other variables preclude the establishment of absolute limits of tolerance of heat that differentiate 'safe' and 'unsafe' levels. One set of recommended heat exposure limits is shown in Figure 2.5. This set of recommendations specifies the permissible heat exposure Threshold Limit Values (TLV), in WBGT units for different workload levels and work-rest schedules.

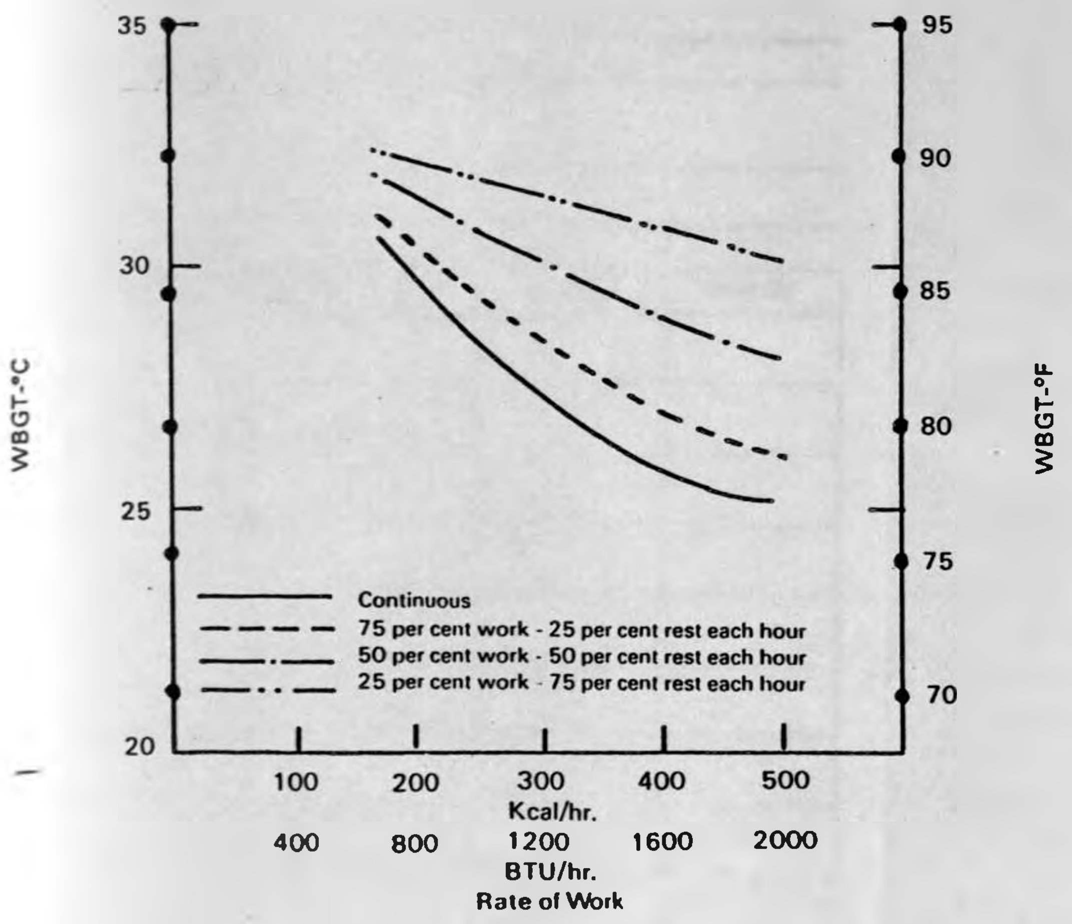


Figure 2.5: Limits of heat exposure.

Source: ILO, 1987.

Although there is reasonable agreement on the acceptable limits of exposure to heat for the conventional 8-h workday, there is considerable divergence of opinion regarding such limits for intermittent work in hot environments when people are subjected to occasional periods of work in hot environments because data about such exposure are limited [Sanders and McComic, 1987]. Higher work rates or environmental temperatures impose additional strain on man's thermoregulatory system. Unless measures are taken to reduce these sources of strain by the introduction of rest pauses in cooler surroundings, there will be an increasing storage of heat within the body, which will result in the eventual heat collapse of the person exposed. The more burdensome the climatic conditions, the longer the work breaks should be.

A physiological index of thermal strain called the predicted 4-h sweat rate (P4SR) has been developed which reflects the stress of working in hot environments for specified periods of time [Luigi, 1989]. For fit, young men, a P4SR value of 41 has been suggested as the upper limit of thermal stress which would permit workers to complete a task lasting 4 hr without the onset of acute heat illness. For unacclimatized persons, the limit of a P4SR value of 31 has been suggested as the upper limit, below which physical work tasks can be completed by majority of workers. Above the two limits, majority of workers will find the conditions intolerable and present symptoms of physiological distress.

2.10 Release of undesirable materials

2.10.1 Dust formation

Another factor that can render working environments unsafe is the release of undesirable materials. Of the various materials released in agro-industries, dust was the major focus in this research. Dust may be defined as a disperse system of heterogeneous solid particles in air whose broad size distribution is predominantly that of a colloid. Airborne dust is ubiquitous and workplaces are no exception; every operation and action releases a certain amount of dust into the air.

Fortunately most dust is harmless but in sufficient concentrations it can cause discomfort and unpleasantness. At such levels it is termed a 'nuisance dust'. However, some dusts are distinctly harmful, giving rise to carcinoma, chronic lung diseases, asthma, bronchitis and other disorders. Not only does the chemical composition of the material and its airborne concentration determine its detrimental effects but also the particle size influences the part of the lungs where the material is deposited.

Dust is classified by size into three primary categories: respirable, inhalable, and total dust. Respirable dust refers to those particles small enough to pass through the nose and upper respiratory system and penetrate deep into the lungs. Particles that penetrate deep into the respiratory system are generally beyond the natural clearance mechanism of the body and are more likely to be retained and cause health problems. These respiratory particles are less than 10 μm in aerodynamic diameter. It is estimated that 25% of these particles less than 5 μm are respirable, while 90% of those particles less than 2 μm are respirable [Luigi, 1989].

Inhalable dust consist of the size fraction larger than respirable dust and has an aerodynamic diameter of 10 μm. Inhalable dust enters the body but is trapped in the nose, throat and upper respiratory tract and usually expelled from the body. Total dust includes all airborne particles, regardless of the size or component.

2.10.2 Dust sampling

Any dust measurement procedure should enable one to detect dust sources and determine their magnitude; check the efficiency of preventive measures that are adopted and; monitor the exposure of the workers to air borne. Therefore sampling and measurement instruments must be capable of collecting and analyzing particles in the size range below 5 μm, including those of 1-2 μm in size [Luigi, 1989]. There are two basic methods of sampling airborne dust: filtration sampling and use of direct reading instruments.

i) <u>Filtration sampling</u>

In filtration sampling, a known volume of air is drawn through a pre-weighed filtering device by means of an air pump. Weighing the filtering device before and after will determine the mass of dust collected. By dividing that mass by the total volume of air drawn through, an average dust concentration is obtained for the sampling period. Filtration systems are available which are lightweight enough for workers to wear to determine their personal exposure to the airborne dust.

The filtration method can also be used to monitor a working area using one static position throughout the sampling period. In this case the equipment should, if possible, be attached to a tripod or fixed object in the area under study. In order to achieve sufficient accuracy it is important to weigh the filters to 0.01 mg.

ii) Direct reading instruments

The second method of sampling involves using an instrument which gives a direct reading of the dust concentration at any instant of time but may or may not give an average over a period of time. Direct reading instruments are more bulky and are unsuited to personal monitoring; they are used to measure a working area rather than an individual.

For a dust sample in an industry to be representative, it should not be taken too close to the origin of the dust; and it is important to choose periods of normal activity, to position the sampling head of the apparatus where the air is most homogeneous and allow sufficient time for the sampling (a minimum of 2 hr). Unless it is wished to study the fluctuations in dust concentration, continuous sampling is, theoretically, better. In total gravimetric sampling, it is advisable to aspirate the dust at a speed comparable to that of the speed of air movement. This is not so imperative for numerical sampling: it is, in practice, impossible in the case of instruments equipped with a pre-separator, and functioning at constant speed.

2.10.3 Dust sample analysis

Dust samples are usually taken to determine concentration, size, chemical composition and, possibly shape of the particles. The different constituents of a given dust sample are usually expressed in terms of percentage by weight, determined by chemical, physical or mineralogical procedures. Examination of dust samples can be carried out by weighing or by particle counting. Dust weight is obtained by weighing the filter before and after sampling (with preliminary drying if possible). To obtain the particle size, the dust is suspended in a liquid, which enables measurement to be made of: the quantity of dust deposited; the variation in the specific weight of the suspended matter; the concentration and the relation to time at a given level; and the variation in electrical resistance of an electrolyte in which the particles are diluted.

Dust concentration is usually expressed in terms of the numbers, the surface area, or the volume (mass or weight) per unit volume of air. In case of industrial dust, the results are generally expressed in weight per cubic meter of air (mg/m^3). It is the total surface area or mass of the particles deposited and not their number which determines the environmental hazard. Selective sampling devices have been developed (especially gravimetric) equipped with an elutriator to collect only the particles termed 'respirable'. Dust concentrations are being increasingly expressed gravimetrically taking into consideration the particles of respirable size, and indicating the proportions by weight of the different constituents e.g. ash, free silica or quartz, as a percentage. The dust concentration in equation form [Luigi, 1989] is expressed as:

$$\text{Concentration} = [W_s \times 1000]/[q \times t] \text{ in } mg/m^3 \quad (2.14)$$

where: W_s = weight of dust sample in mg;

q = pump flow rate in l/min.;

t = Sampling time in min.

2.10.4 Effects of dust exposure

There are two distinct hazards associated with industrial dust: the explosion hazard and the health hazard.

i) Dust explosion.

Any combustible solid materials, in finely divided form, can give rise to dust explosion hazard. All that is necessary is for the dust to become suspended in air in sufficient concentration and to be subjected to a source of ignition. Often dust, formed from generally considered non-flammable materials, is highly flammable and often explosive. This is due to the relative proportions of oxygen present in a dust/air mixture. For this reason it is of paramount importance to maintain high standards of cleanliness and house-keeping in the vicinity of all dust producing processes

The hazard of dust explosion is encountered with many materials of natural origin (e.g. sugar, flour), plastics and organic chemicals. Any accumulation of dust dislodged near an ignition source can lead to a fire of an explosive nature in an ill-kept work place. Dust explosion are normally in two stages: a primary explosion from a local dust cloud followed by a major secondary explosion due to accumulations of settled dust being dispersed into clouds by the primary explosion.

ii) Health hazard

The extent to which any type of dust represents a health risk depends on exposure, which includes the nature of the dust, its concentration, and duration of exposure. It also depends upon individual factors such as the general constitution and state of health of the person concerned, including the functional state of the upper respiratory tract, the lung function and its structure, the general immunological status and specific immunological reactivity, and the biochemical reactivity. All these factors will play a part in the onset of disease [Luigi, 1989].

The effects of dust on the body vary with the nature of the dust. Fine particles of toxic substances suspended in air may be deposited on the skin and mucus membranes causing irritation, sensation, ulceration or even cancer. Plant dust (organic) typically occurring in agro-industries was the major concern in this research. Plant dust (as in sugar industries - from the bagasse) have the property of giving rise to allergic reactions e.g. allergies of the respiratory tract (Bronchial asthma or alvaeolitis). The handling of bagasse, especially dump bagasse, causes a fungal related disease known as Bagassiosis.

2.11 Subjective response

Each of the four environmental factors (air temperature, radiant temperature, air velocity and humidity) that determine the heat exchange process is involved in its own "balance" and efforts by several researchers to find a unit measurement that would take account of them all have been unsuccessful. Research workers have therefore tied environmental measurements with subjective impressions of test persons to fully define the working environment.

Two types of surveys can be employed for the collection of subjective information: the informal survey and the formal survey. The informal surveys normally involve chats with the target group and an interview guide is normally of great value in this case. Formal surveys normally employ a questionnaire. The particular values of questionnaires are: to measure psychological consequences of the environment and give an insight of subsequent behaviour of the people concerned; they allow fairly rapid access to the previous history leading up to the particular problem under study; and they give quantitative access to the people's subjective judgement.

CHAPTER 3: METHODOLOGY

3.1 The study sites

The research was confined to the factory area, and to accomplish the objectives of the study, three sections were selected in the factory: the Process house and the Boiler house for the study of the effects of Hot working environments; and the Bagasse store with its surroundings for the study of the effects of personnel exposure to dusty environments.

3.1.1 Process house

The filtration and the purification processes in the process house give off more heat than any other process. The evaporators and the vacuum pans are used for these processes and it is the working environment around them that was of interest. Figure B1 of Appendix B shows the Process house layout with the sites that were of major concern.

3.1.2 Boiler house

The great majority of the bagasse produced in a sugar cane mill supplies the fuel for the generation of steam. The bagasse is carried directly from the mills to the boilers for the production of this steam. In the process of generating steam, a lot of heat is normally given off, rendering the working environment hot. The areas of concern therefore were the workplaces within this working environment where workers spent most of the time during an 8-hr shift controlling the boilers. Figure B2, Appendix B, shows the layout of these boilers and the sites as they were chosen.

3.1.3 Bagasse house

The bagassilo from the bagasse house floats the entire company premises, with the areas in the immediate vicinity of the bagasse store being the most affected. With all the dangers attributed to the exposure to the bagassilo, three sets of operators were more exposed to them than the other workers: the control panel operators, the tractor operators, and the bagasse store attendant. Figure B3, Appendix B, shows the workplaces of the operators.

3.1.4 Activities at the study sites

In order to achieve the objectives of the research, the following activities were undertaken:

1. Measurement of environmental components in the process house and boiler house;
2. Taking dust samples to determine the concentration and monitor exposure of personnel to airborne dust;
3. Determination of the thermal (heat) exchange between personnel and their respective working environment to ascertain the workers' working comfort or discomfort;
4. Developing a questionnaire for the collection of subjective response from workers;
5. Assessment of existing layout of workplaces so as to develop recommendations for safe working areas.

3.2 Materials and Equipment

3.2.1 Air Temperature measurements

A thermocouple digital thermometer (DT 6020) was used for the determination of air temperature, using a k-type thermocouple with an accuracy of ±0.1% for temperatures less than 100°C and ±0.4% for temperatures greater than 100°C. The digital thermometer allowed reading of any rapid changes in the environment.

3.2.2 Radiant temperature measurements

A venon globe thermometer, which consisted of a hollow metal globe, six inches in diameter, coated with matt black paint, and a five inch immersion thermometer was used. The thermometer was placed in the globe in such a way that its bulb was at the center of the globe. A time lag of 20 min. was allowed for the instrument to come to equilibrium with the environment before taking the reading.

3.2.3 Relative Humidity measurements

The digital humidity/temperature meter was used for the establishment of relative humidity levels. The meter has the advantage of being able to record any rapid changes in the environment and gives instantaneous readings within the range of 20 - 90% .

3.2.4 Air movement measurement

The vane ananometer was used for the instantaneous determination of the air movement. The instrument had a range of 0 to 3 m/s.

3.2.5 Dust sampling equipment

Different types of apparatus were used for personal and fixed position sampling. The basic features for both systems were a filter (on which the sample was collected) and a pump for sucking the air through it; and the filter holder.

i) <u>Personal sampling</u>

A cyclone preselector pump (S 125) with an air flow rate of 0.21 litres/min. was used, with a minimum sampling time of 4 hr being allowed for each sample.

ii) Fixed position sampling

A permissible portable pump with an open-faced filter holder, and a pump unit capable of maintaining 2.0 litres/min. was used, and a sampling time of 2 hr was allowed for each sample.

3.2.6 Subjective response

Both formal and informal surveys were carried out. The questionnaire (presented in Appendix A1) targeted three departments: the safety/maintenance department, the company clinic and the factory. The objectives of the questionnaire were: to establish the psychological and physical consequences of hot and dusty working environments, and access previous history leading up to unsafe working conditions as well as statistics of reported accidents.

Since the factory presented a wide spectrum of workers, the informal survey was necessary especially for the workers who were not comfortable with paper work. The informal survey also led to the access of information of incidents that never got reported, but yet rendered the working environment unsafe. This survey was geared mainly at the shop-floor workers.

3.3 Methods

3.3.1 Thermal environment measurement

The objective of the thermal environment measurement was to make valid, accurate and thorough measurements which clearly represented the thermal situation in the Process house and the Boiler house workplaces so as to evaluate the thermal load/stress imposed on the exposed workers. The procedure was as follows:

a) Choice of checkpoints

A suitable number of measuring points were chosen at the hot working sections along the sugar processing line so that representative thermal evaluation could be made. A total of nine checkpoints were chosen in the Process house: two at the stream A evaporators (E_{A1B} and E_{A4}); two at stream B evaporators (E_{B2} and E_{B3}); two at the Lower pan floor (P_2 and $P_{5/6}$); and three at the Upper pan floor (P_7, P_9 and P_{11}). In the Boiler house, two points were chosen at the new set of boilers (B_{1B} and B_{2B}). No point was chosen at the old set of boilers as these were not in operation all the time. In most cases they were used as standby boilers in case the new ones stripped. Some of these checkpoints are shown in Plates 3.1 and 3.2.

b) Measured parameters

At every checkpoint that was selected, four parameters were measured: air temperature, radiant temperature, air velocity, and relative humidity. Mumias Sugar Company being a 24-hr operational factory, it was necessary to make measurements both during day and night time to fully define the existing working environment for the normal hours of operation. The equipment given in Section 3.2.1 to 3.2.4 was used for the measurement. Data was taken at an interval of 2 hr and at each sampling point, four replications were made for each parameter for every sampling time and an average of these four readings was taken to be representative of the parameter measured.

3.3.2 Dust sampling

The objective of dust sampling was to verify whether personal exposure exceeded the relevant limit and to measure levels within the workplaces. The procedure was as follows:

a) Personal samples

The bagasse store attendants were chosen for the personal samples because they were exposed to the bagasse for longer hours than any other workers. The Personal samples were taken using a fully charged battery operated portable sampling pump shown in Plate

3.3 (a). The test persons were provided with a suitable belt to which the pump was fixed (Plate 3.3 (b)). The sampling head (Fig. 3.1) was attached to the test persons 30 cm away from the nose-mouth region. The time was recorded at the start of the sampling period and end of sampling, a minimum of 4 hr being allowed for each sample and two replications were taken for these personal samples. At the end of the sampling period, the pump was switched off and then the filter removed, with dust side uppermost. The filters were then mounted in small cassettes to prevent unintentional disturbance of the filters and damage. The cassettes facilitated the transportation of the filters to the analysis laboratory.

b) Fixed point sampling

Particular care was given to the positioning of fixed point samplers so as to obtain a representative sample of dust. Six workplaces that appeared to be most affected with the floating bagassilo were selected for the fixed position sampling and they included the bagasse store platform, outside the Bagasse tower, outside the foundry, between the boiler house and the workshop, the old boiler house (boilers 1 and 2) and boilers 3 and 4. The sampler was suspended at approximately head height and away from obstructions and potential air inlets (Plate 3.5). Time was recorded at the start and end of the sampling period, 2 hr being allowed for each sample and two replications were used for each sampling position. The filters were carefully removed, with dust side uppermost, and mounted into cassettes at the end of the sampling period ready for transportation to the analysis laboratory.

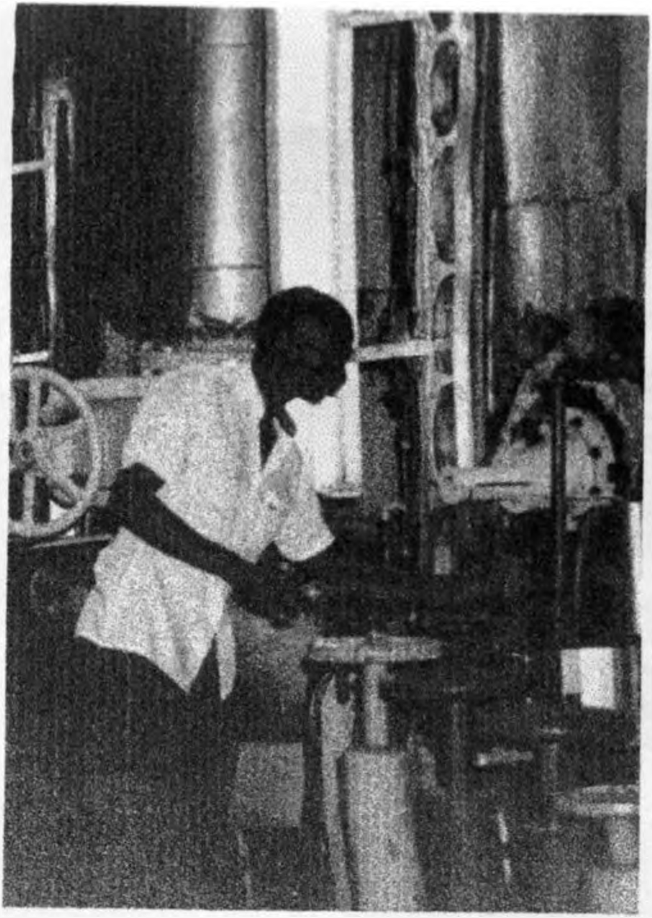
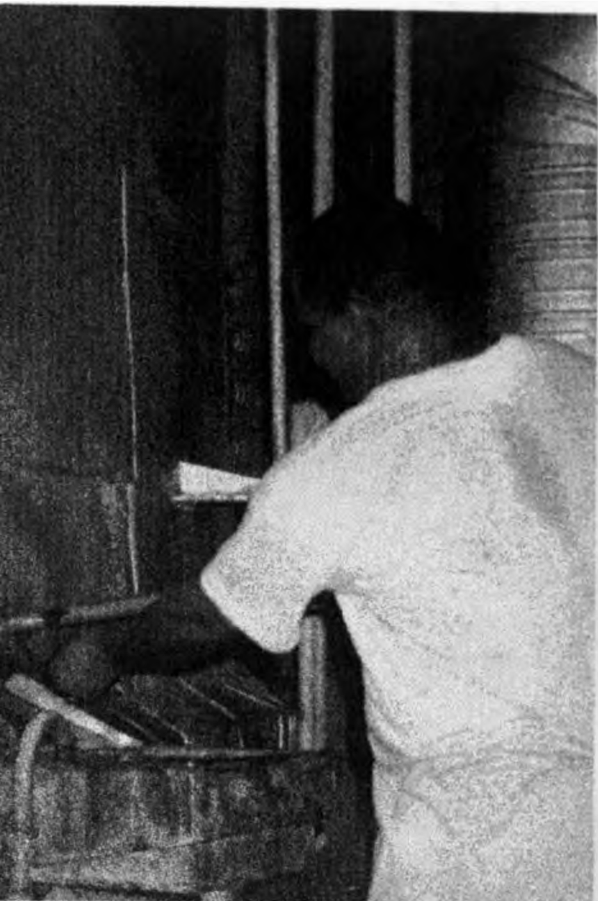


Plate 3.1: Process House Checkpoints



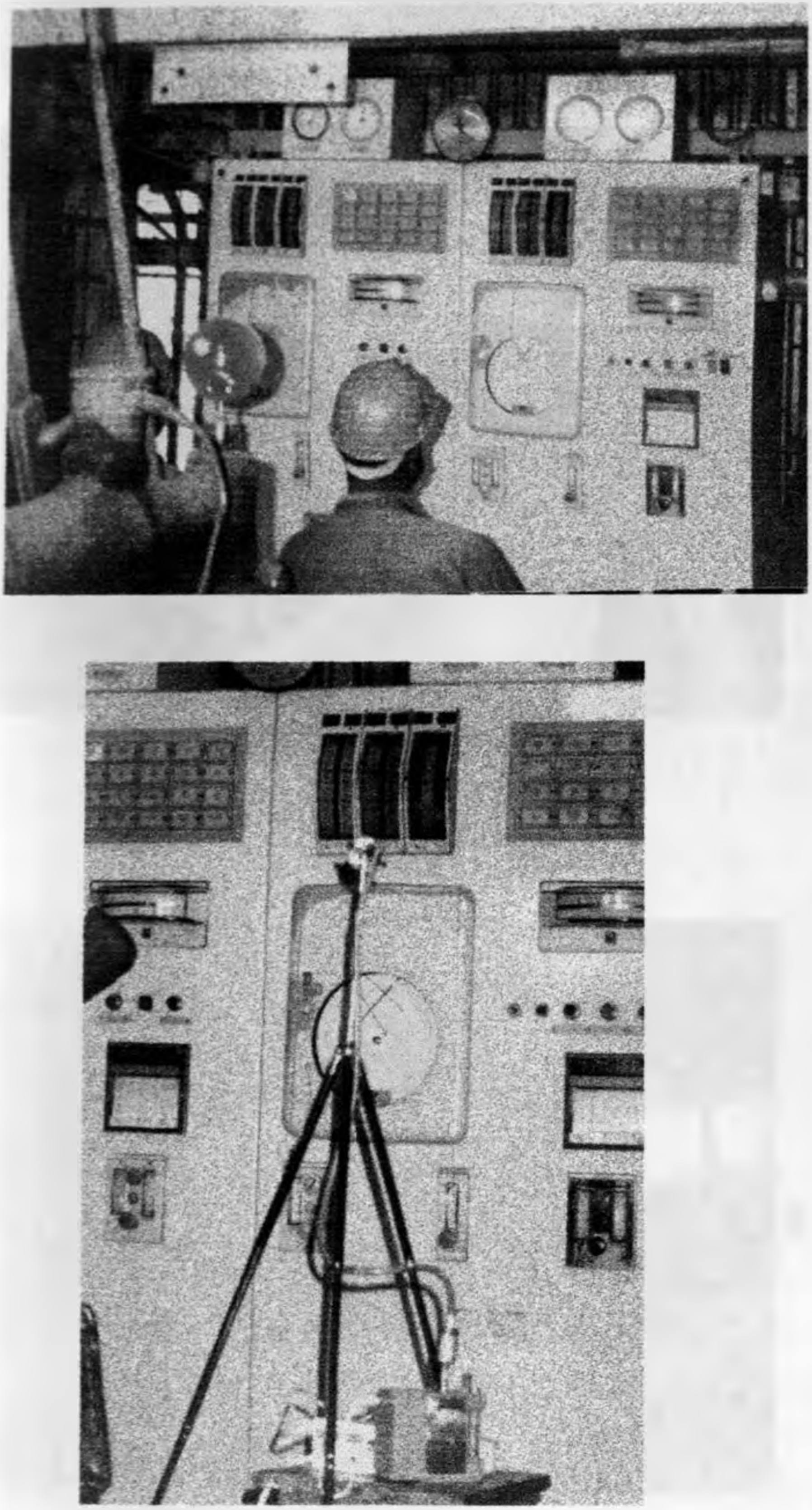
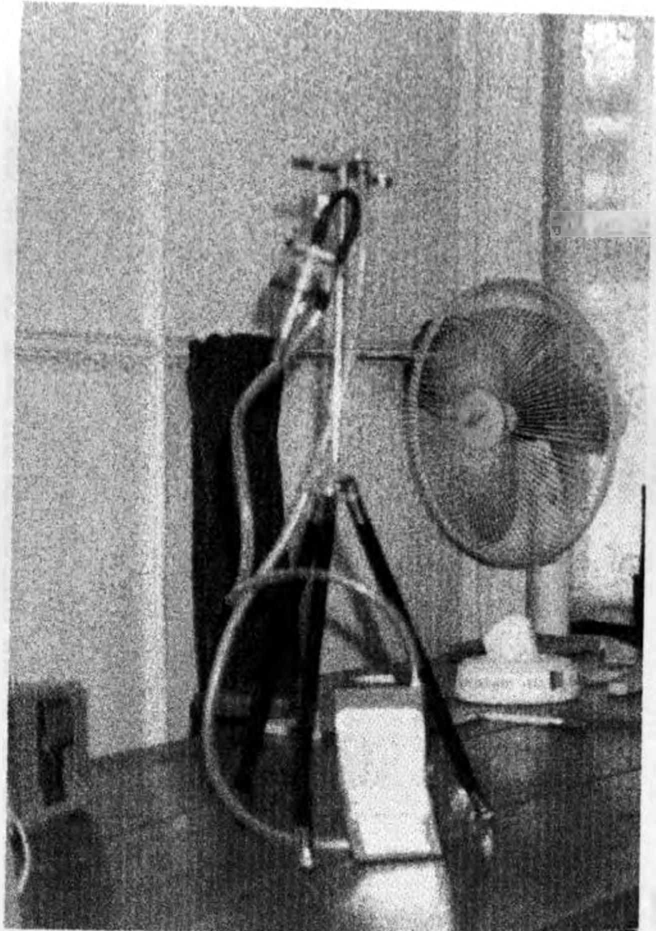


Plate 3.2: Boiler House Checkpoints



(a)

Plate 3.3: Personal Sampling Equipment

(b)

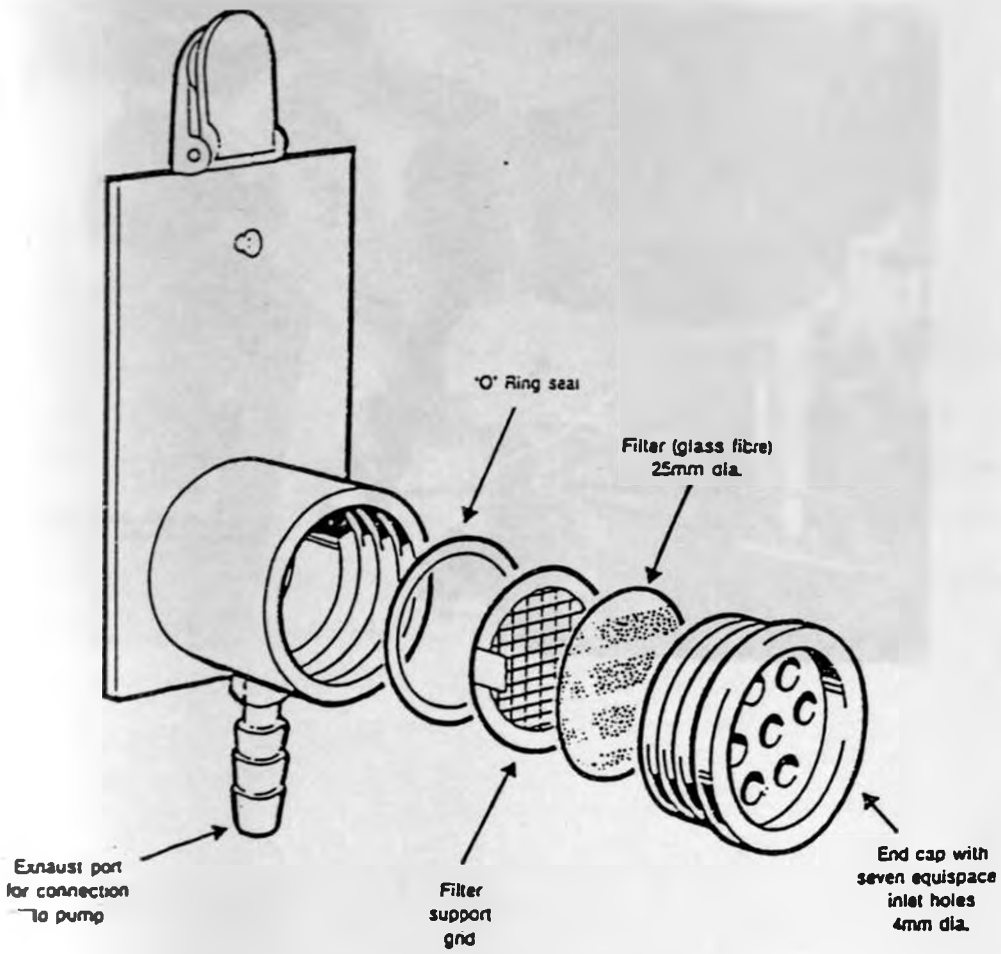


Figure 3.1: Personal sampling head used for gravimetric dust sampling

3.3.3 Subjective response

The population that was chosen was Mumias Sugar Company workers and the samples were drawn from the company clinic, safety department, and the factory, i.e., stratification with random sampling was used to improve the representativeness of the sample whereby the departments formed the strata.The sample sizes were 8 for the Maintenance/Safety department, 5 for the clinc and 30 for the factory department. The number of questionnaires recovered were 7, 3 and 22 for the Maintenance/safety, Clinic and Factory department respectively

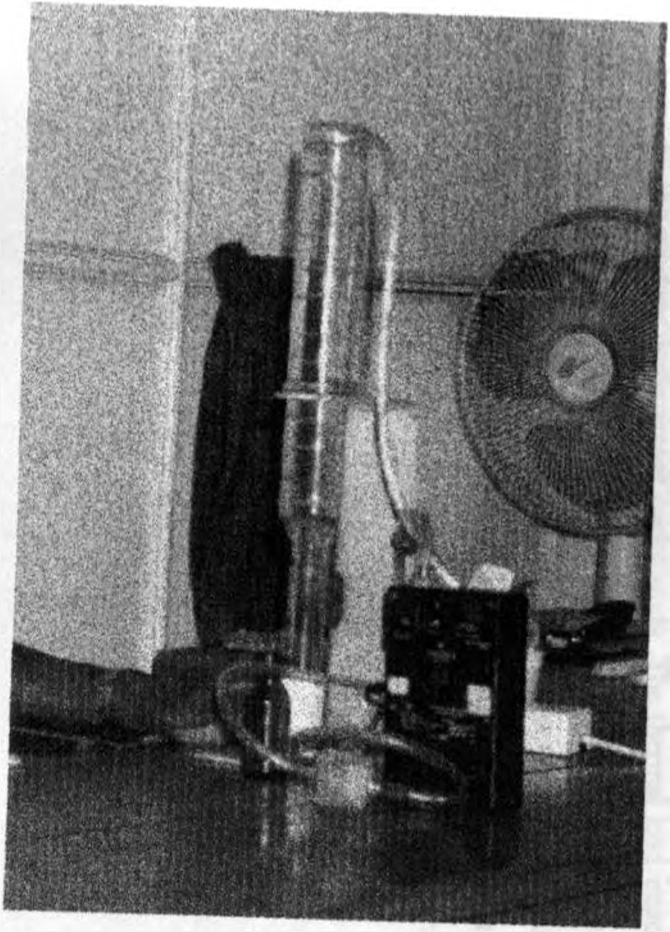


Plate 3.4: Apparatus for calibrating the sampling pumps

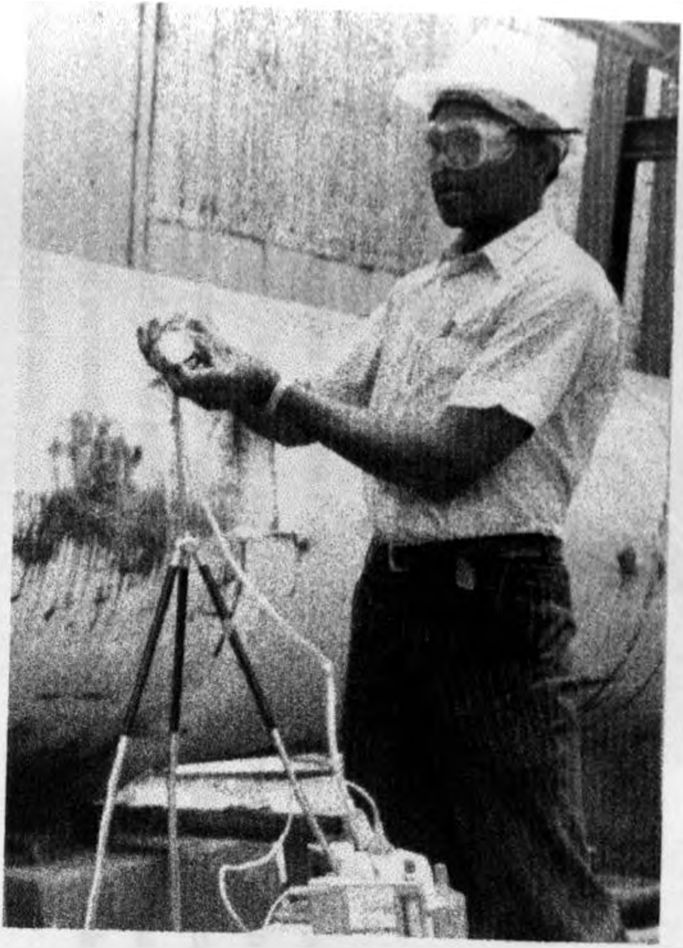


Plate 3.5: Set-up of the Fixed position sampling equipment

CHAPTER 4: RESULTS, ANALYSIS AND DISCUSSION

4.1 Thermal environment

4.1.1 Results of the study

Thermal environment data obtained in the Process house and Boiler house is presented in Tables 1 to 10, Appendix C, for both day and night time measurements. The data includes the four environmental components namely air temperature, radiant temperature, air velocity, and relative humidity. Other parameters required for the evaluation of thermal load imposed on the exposed personnel, which included weight and height of selected test persons, were also noted in the study.

4.1.2 Analysis of data

a) Theoretical Analysis

The data obtained in the study was used to establish the thermal environmental balance associated with the working environment under study. The thermal load imposed on the exposed personnel for the various hours of sampling was evaluated using equations in Section 2.8 with the aid of a Pascal Program. The Program, presented in Appendix D2, was developed from the flow chart shown in Appendix D1. The results of the evaluated thermal load, along with all the other calculated parameters that were required for the evaluation of the thermal load, are presented in Table 4.1.

Table 4.1: Thermal load imposed on exposed personnel

Time	Point	t_{cr}	t_{sk}	rc	S
0800	E_{A1}	38.1	36.0	-19.78	63.71
	E_{A4}	34.8	35.1	2.14	41.78
	E_{B2}	31.1	34.1	29.80	14.14
	E_{B3}	31.5	34.2	28.49	15.44
	P_2	31.0	34.1	31.15	12.79
	$P_{5/6}$	30.7	34.0	32.46	11.47
	P_7	29.6	33.7	48.20	-4.27
	P_9	29.0	33.6	45.21	-1.28
	P_{11}	29.7	33.7	38.58	5.35
	B_{1B}	28.4	33.4	49.72	-5.79
	B_{2B}	27.1	33.0	65.91	-21.98
1000	E_{A1}	42.5	37.1	-47.01	90.95
	E_{A4}	38.0	36.0	-20.06	64.00
	E_{B2}	35.8	35.4	-5.69	49.62
	E_{B3}	36.4	35.5	-10.56	54.50
	P_2	35.6	35.3	-2.80	46.73
	$P_{5/6}$	34.2	34.9	6.20	37.73
	P_7	35.8	35.4	-4.16	48.10
	P_9	35.3	35.2	-0.54	44.47
	P_{11}	34.0	34.9	8.25	35.68
	B_{1B}	33.4	34.7	12.77	31.16
	B_{2B}	32.3	34.4	20.07	23.86
1200	E_{A1}	44.3	37.6	-62.11	106.04
	E_{A4}	40.9	36.7	-35.09	79.02
	E_{B2}	39.6	36.4	-41.69	85.62
	E_{B3}	40.6	36.6	-42.13	86.07
	P_2	39.9	36.5	-32.69	76.62
	$P_{5/6}$	38.8	36.2	-34.71	68.64
	P_7	37.9	35.9	-23.68	67.61
	P_9	37.1	35.7	-16.95	60.88
	P_{11}	37.6	35.8	-19.05	62.98
	B_{1B}	36.1	35.4	-6.85	50.78
	B_{2B}	35.2	35.2	-0.02	43.95

Table 4.1 Cont'd

1400	E_{A1}	47.4	38.4	-91.45	135.38
	E_{A4}	43.8	37.5	-58.82	102.76
	E_{B2}	42.5	37.1	-59.16	103.10
	E_{B3}	42.8	37.2	-55.29	99.22
	P_2	42.8	37.2	-50.14	94.07
	$P_{5/6}$	40.4	36.6	-45.18	89.11
	E_{B3}	40.8	36.7	-48.18	92.11
	P_2	39.7	36.4	-41.87	85.81
	$P_{5/6}$	39.4	36.3	-33.74	77.68
	B_{1B}	39.1	36.2	-28.48	72.41
	B_{2B}	38.7	36.1	-28.79	72.72
1600	E_{A1}	45.9	38.0	-100.47	144.40
	E_{A4}	42.9	37.3	-60.69	104.62
	E_{B2}	41.5	36.9	-60.85	104.79
	E_{B3}	42.0	37.0	-64.14	108.07
	P_2	41.7	36.9	-58.46	102.39
	$P_{5/6}$	40.6	36.6	-53.71	97.64
	P_7	39.3	36.3	-45.24	89.17
	P_9	39.7	36.4	-41.49	85.42
	P_{11}	40.6	36.6	-42.74	86.67
	B_{1B}	37.7	35.9	-16.41	60.34
	B_{2B}	37.5	35.8	-18.33	62.26
2000	E_{A1}	40.6	36.6	-35.82	79.75
	E_{A4}	38 0	35.9	-19.06	63.00
	E_{B2}	34.1	34.9	9.81	34.12
	E_{B3}	35.1	35.2	0.95	42.98
	P_2	36.7	35.6	-12.17	56.10
	$P_{5/6}$	39.1	36.3	-29.49	73 42
	P_7	37.8	35.9	-24.17	68.10
	P_9	38.6	36.1	-29.35	73.29
	P_{11}	38.8	36.2	-28.51	72.45
	B_{1B}	32.6	34.5	18.79	25.14
	B_{2B}	32.5	34.5	20.61	23.32

Table 4.1 Cont'd

2200	E_{A1}	41.3	36.8	-34.12	78.05
	E_{A4}	38.2	36.0	-18.74	62.67
	E_{B2}	34.1	34.9	8.80	35.14
	E_{B3}	34.3	35.0	5.78	38.15
	P_2	36.6	35.6	-9.69	53.62
	$P_{5/6}$	35.9	35.4	-5.42	49.35
	P_7	36.0	35.4	-6.83	50.76
	P_9	36.9	35.6	-11.57	55.50
	P_{11}	37.0	35.7	-12.31	56.24
	B_{1B}	30.6	34.0	35.52	8 41
	B_{2B}	30.7	34.0	32.61	11.32
2400	E_{A1}	37.4	35.8	-13.78	57.72
	E_{A4}	34.1	34.9	8.03	35.90
	E_{B2}	33.1	34.6	17.90	26.04
	E_{B3}	32.9	34.6	19.11	24.83
	P_2	34.2	34.9	6.98	36.95
	$P_{5/6}$	31.7	34.3	27.15	16.78
	P_7	35.2	35.5	-0.37	44.30
	P_9	35.8	35.4	-4.46	48.39
	P_{11}	35.6	35.3	-3.15	47.08
	B_{1B}	30.5	33.9	31.95	11.98
	B_{2B}	30.1	33.8	36.70	7.24
0200	E_{A1}	36.3	35.5	-6.50	50.43
	E_{A4}	33.0	34.6	14.48	29.45
	E_{B2}	31.1	34.1	33.37	10.57
	E_{B3}	31.7	34.3	25.40	18.53
	P_2	31.8	34.3	24.63	19.30
	$P_{5/6}$	31.8	34.3	25.77	18.16
	P_7	32.1	34.4	25.90	18.03
	P_9	32.2	34.4	22.01	21.92
	P_{11}	32.8	34.5	17.41	26.52
	B_{1B}	28.6	33.4	48.07	-4.14
	B_{2B}	28.8	33.5	44.77	-0.84

Table 4.1 Cont'd

0400	E_{A1}	31.2	34.1	28.36	15.57
	E_{A4}	31.1	34.1	25.95	17.98
	E_{B2}	29.9	33.8	48.01	-4.08
	E_{B3}	30.8	34.0	33.74	10.19
	P_2	30.3	33.9	41.62	2.31
	$P_{5/6}$	30.6	34.0	33.17	10.76
	P_7	30.6	34.0	43.94	-0.01
	P_9	30.3	33.9	40.58	3.36
	P_{11}	30.4	33.9	34.41	9.52
	B_{1B}	28.0	33.3	54.66	-10.73
	B_{2B}	28.2	33.3	50.46	-6.53

b) Statistical analysis

The least significant difference (lsd) was used to compare the heat load imposed on the workers for the 11 sampling points at the different times of sampling. The lsd test criterion involved the computation of the smallest difference at a 5% significant level, which was declared significant, and the absolute value of each observed difference was compared with it. The means of the thermal load were ranked from smallest to largest and the differences are presented in Table 4.3 to 4.12. The lsd was evaluated using equation (4.1).

$$lsd(\alpha) = t_{\alpha/2} s\sqrt{2/r} \qquad (4.1)$$

where: α = significant level;

s = standard deviation of the means;

r = replication.

The lsd for the different times of sampling for $t_{(0.025)} = 3.182$ and r = 4 is presented is Table 4.2. All the significant differences are indicated by " * " and figures without any mark indicate non-significant differences.

Table 4.2: The lsd for the various hours of sampling

Time	s	lsd
0800	23.53	52.93
1000	18.12	39.51
1200	17.56	34.47
1400	17.81	40.06
1600	23.09	51.94
2000	20.73	46.65
2200	20.94	47.11
2400	16.37	36.82
0200	14.71	33.10
0400	9.24	20.80

Table 4.3: Differences between 0800 hr mean thermal loads

	-5.79	-4.27	-1.28	5.35	11.47	12.79	14.14	15.44	41.78	63.71
-21.98	16.19	17.71	20.70	27.33	33.45	34.77	36.12	37.42	63.76*	85.69*
-5.79		1.52	4.51	11.14	17.26	18.58	19.93	21.23	47.57	69.50*
-4.27			2.99	9.62	15.74	17.06	18.41	19.71	46.05	67.98*
-1.28				6.63	12.75	14.07	15.42	16.72	43.06	64.99*
5.35					6.12	7.44	8.79	10.09	36.43	58.36*
11.47						1.32	2.67	3.97	30.31	52.24
12.79							1.35	2.62	28.99	50.92
14.14								1.30	27.64	49.57
15.44									26.34	48.27
41.78										21.93

Table 4.4: Differences between the 1000 hr mean thermal loads

	31.16	35.68	37.73	44.47	46.73	48.10	49.62	54.50	64.00	90.95
23.86	7.30	11.82	13.87	20.61	22.87	24.24	25.76	30.64	40.14*	67.09*
31.16		4.52	6.57	13.31	15.57	16.94	18.46	23.34	32.84	59.79*
35.68			2.05	8.79	11.05	12.42	13.94	18.82	28.32	55.27*
37.73				6.74	9.00	10.37	11.89	16.77	26.27	53.24*
44.47					2.26	3.63	5.15	10.03	19.53	46.48*
46.73						1.37	2.89	7.77	17.27	44.22*
48.10							1.52	6.40	15.90	42.85*
49.62								4.88	14.38	41.33*
54.50									9.50	36.45
64.00										26.96

Table 4.5: Differences between the 1200 hr mean thermal loads

	50.78	60.88	62.98	67.61	68.64	76.62	79.02	85.62	86.07	106.04
43.95	6.83	16.93	19.03	23.66	24.69	32.67	35.07*	41.67*	42.12*	62.09*
50.78		10.10	12.20	16.83	17.86	25.84	28.24	34.84*	35.29*	55.26*
60.88			2.10	6.73	7.76	15.74	18.14	24.74	25.19	45.16*
62.98				4.63	5.66	13.64	16.04	22.64	23.09	43.06*
67.61					1.03	9.01	11.41	18.01	18.46	38.43*
68.64						7.98	10.38	16.98	17.43	37.40*
76.62							2.40	9.00	9.45	29.42
79.02								6.60	7.05	27.02
85.62									0.45	20.42
86.07										19.97

Table 4.6: Differences between the 1400 hr mean thermal loads data.

	72.72	77.68	85.81	89.11	92.11	94.07	99.22	102.76	103.10	135.38
72.41	0.31	5.27	13.40	16.70	19.70	21.66	26.81	30.35	30.69	62.97*
72.72		4.96	13.09	16.39	19.39	21.35	26.50	30.04	30.38	62.66*
77.68			8.13	11.43	14.43	16.39	21.54	25.08	25.42	57.70*
85.81				3.30	6.30	8.26	13.41	16.95	17.29	49.57*
89.11					3.00	4.96	10.11	13.65	13.99	46.27*
92.11						1.96	7.11	10.65	10.99	43.27*
94.07							5.15	8.69	9.03	41.31*
99.22								3.54	3.88	36.16
102.76									0.34	32.62
103.10										32.28

Table 4.7: Differences between the 1600 hr mean thermal loads

	62.62	85.42	86.67	89.17	97.64	102.39	104.62	104.79	108.07	144.40
60.34	1.92	25.08	26.33	28.83	37.30	42.05	44.28	44.45	47.73	84.06*
62.26		23.16	24.42	26.91	35.38	40.13	42.36	42.53	45.81	82.14*
85.42			1.25	3.75	12.22	16.97	19.20	19.37	22.65	58.98*
86.67				2.50	10.97	15.72	17.95	18.12	21.40	57.73*
89.17					8.47	13.22	15.45	15.62	18.90	55.23*
97.64						4.75	6.98	7.15	10.43	46.46
102.39							2.23	2.40	5.68	42.01
104.62								0.17	3.45	39.78
104.79									3.28	39.61
108.07										36.33

Table 4.8: Differences between the 2000 hr mean thermal loads

	25.14	34.12	42.98	56.10	63.00	68.10	72.45	73.29	73.42	79.75
23.32	1.82	10.80	19.66	32.78	12.68	44.78	49.13*	49.97*	50.10*	56.43*
25.14		8.98	17.84	30.96	37.86	42.96	47.31*	48.15*	48.28*	54.61*
34.12			8.86	21.98	28.88	33.98	38.33	39.17	39.30	45.63
42.98				13.12	20.02	25.12	29.47	30.31	30.44	36.77
56.10					6.90	12.00	16.35	17.19	17.32	23.65
63.00						5.10	9.45	10.29	10.42	16.75
68.10							4.35	5.19	5.32	11.65
72.45								0.84	0.97	7.30
73.29									0.13	6.46
73.42										6.33

Table 4.9: Differences between the 2200 hr mean thermal loads

	11.32	35.14	38.15	49.35	50.76	53.62	55.50	56.24	62.67	78.05
8.41	2.91	26.73	29.74	40.94	42.35	45.21	47.09	47.83*	54.26*	69.64*
11.32		23.82	26.83	38.03	39.44	42.30	44.18	44.92	51.35*	66.73*
35.14			3.01	14.21	15.62	18.48	20.36	21.10	27.53	42.91
38.15				11.20	12.61	15.47	17.35	18.09	24.52	39.90
49.35					1.41	4.27	6.15	6.89	13.32	28.70
50.76						2.86	4.74	5.48	11.91	27.29
53.62							1.88	2.62	9.05	24.43
55.50								0.74	7.17	22.55
56.24									6.43	21.81
62.67										15.38

Table 4.10: Differences between the 2400 hr mean thermal loads

	11.98	16.78	24.83	26.04	35.90	36.95	44.30	47.08	48.39	57.72
7.24	4.74	7.54	17.59	18.80	28.66	29.71	37.06*	39.84*	41.15*	50.48*
11.98		4.80	12.85	14.06	23.92	24.97	32.32	35.10	36.41	45.74*
16.78			8.05	9.26	19.12	20.17	27.52	30.30	31.61	40.94*
24.83				1.21	11.07	12.12	19.47	22.25	23.56	32.89
26.04					9.86	10.91	18.26	21.04	22.35	31.68
35.90						1.05	8.40	11.18	12.49	21.82
36.95							7.35	10.13	11.44	20.77
44.30								2.78	4.09	13.42
47.08									1.31	10.64
48.39										9.33

Table 4.11: Differences between the 0200 hr mean thermal loads

	-0.84	10.57	18.03	18.16	18.57	19.30	21.92	26.52	29.45	50.43
-4.14	3.30	14.71	22.17	22.30	22.71	23.44	26.06	30.66	33.59*	54.57*
-0.84		11.41	18.87	19.00	19.41	20.14	22.76	27.36	30.29*	51.27*
10.57			7.46	7.59	8.00	8.73	11.35	15.95	18.88	39.89*
18.03				0.13	0.54	1.27	3.89	8.49	11.42	32.40
18.16					0.41	1.14	3.76	8.36	11.29	32.27
8.57						0.73	3.35	7.95	10.88	31.86
19.30							2.62	7.22	10.15	31.13
21.92								4.60	7.53	28.51
26.52									2.93	23.91
29.45										20.98

Table 4.12: Differences between the 0400 hr mean thermal loads

	-6.53	-4.08	-0.01	2.31	3.36	9.52	10.19	10.76	15.57	17.98
-10.73	4.20	6.65	10.72	12.86	14.09	20.25	20.92*	21.49*	26.30*	28.71*
-6.53		2.45	6.52	8.84	9.89	16.05	16.72	17.29	22.10*	24.51*
-4.08			4.07	6.39	7.44	13.60	14.27	14.84	19.65	22.06*
-0.01				2.32	3.37	9.53	10.20	10.77	15.58	17.99
2.31					1.05	7.21	7.88	8.45	13.26	15.67
3.36						6.16	6.83	7.40	12.21	14.62
9.52							0.67	1.24	6.05	8.46
10.19								0.57	5.38	7.79
10.76									4.81	7.22
15.57										2.41

4.1.3 Discussion of results

From Literature, it was noted that at temperatures of 23.9°C physical fatigue will begin and mental activities will slow down at 29.4°C. Above 30°C hand strength decreases while temperatures above 43.5°C are fatal. All the day time readings for the 11 points investigated ranged between 25 and 40°C. Although none presented fatal conditions, all exceeded the minimum thermal standards suggested for air temperatures, i.e., 24°C. With the exception of the evaporators - A stream, the other points presented conditions within the modular comfort envelop or slightly near the upper limit of the envelop (24 - 27°C) only for the 0800 hr reading. Thereafter, all readings presented conditions capable of slowed down mental activities, increased physical fatigue and decreased limb strength. Evidence of some of these effects was registered in the results of the questionnaire. The exceptionally high temperatures for the evaporators - A stream in comparison to the other points was contributed by the their orientation with respect to the A stream heaters (only 2m apart). The evaporators - B stream on the other hand are 4.7m away from the B stream heaters, hence a less effect than the A stream.

The vacuum pans - Lower floor had their temperatures influenced by the syrup and molasse box temperatures (2.5m apart) and as such readings were higher than those for the Upper floor whose working area is on the opposite side of the syrup and molasse boxes on this floor. Also, the worn out insulation of the evaporators also contributed to the heat generated on the lower pan floor (see Plate 3.1). The temperatures in the Boiler house were considerably lower compared to those for Process house due to the cooling effect attributed to the fairly open set-up of the workplace.

The radiant temperatures followed a similar trend as the air temperatures, ranging between 28 and 51°C, still with the evaporators - A stream registering the highest readings and the Boiler house with the lowest. The present situation of the workplace environment was made worse by the lack of proper protective thermal wear. Currently, the workers are only provided with ordinary over-all or over-coats which are not ideal for Hot working environments.

Likewise, the air velocities were affected by the orientation of the workplaces. Air movement for the A stream evaporators was restricted by the heaters and as such reduced the cooling effect of the operators. In the working areas for the B stream evaporators and the Upper pan floor, the air movement was boosted by the partial openings in the enclosing structures of the building. This led to a better cooling effect. Air movement in the Boiler house was somewhat restricted by the orientation of the boiler house in relation to the Bagasse carrier and the boiler chimney.

Relative humidity *per se* has no meaning as an environmental index without the knowledge of the accompanying air temperature. A combination of the two presented hot-dry working conditions. Only the 1200 and 0200 hr readings of relative humidity fell out of the suggested thermal standards (30 - 60%, ASHRAE standards) for all the 11 points.

A reverse trend was noted for the night time measurements to that of day time readings as can be noted from the data in Tables 6 to 10, Appendix B. Higher temperatures and relative humidities were noted in the early hours of the night and a decrease towards dawn with a range of 25°C to 36°C air temperatures and 34 - 53% relative humidity. Still the Process house presented higher temperatures than the boiler house, with the evaporator - A stream registering the highest. The radiant temperature ranged between 30°C to 44°C.

A combination of these thermal parameters likewise resulted in a higher heat load imposed on the Process house operators than the Boiler house operators. And, as the questionnaire results revealed, these operators had more complaints of heat effects than their counter parts. The most affected were the evaporators operators. The positive values of S imply that the workers were gaining heat from the surrounding and the negative values imply a heat loss to the surrounding. Values of heat loss to the surrounding were registered at 0800 in the boiler house and upper pan floor workplaces and were a result of the combination of lower air temperatures (25.8 - 27.30C) and radiant temperature (28.4 - 31.40C) as compared to the other workplaces.

The statistical analysis was aimed at comparing the thermal loads for the various sampled areas to determine the significance of the observed values. From the analysis for the 0800 o'clock data, the thermal load for the E_{A1} workplace was significantly different from that which existed in the Boiler house and Upper pan floor working areas. Also the thermal load for the E_{A4} workplace was significantly different from that of B_{2B}. The significant difference was attributed to the high air temperatures and radiant temperatures that existed at the stream A evaporators.

For the 1000 hr data, significant differences were registered between the E_{A1} thermal load and that of all the other sampled workplaces with the exception of E_{B3} and E_{A4} where the temperatures were also comparably high as those at E_{A1}. The thermal load at E_{A4} was also significantly different from that at B_{2B}. The 1200 hr data had less significant differences registered between the thermal load for the stream A evaporators and the rest of the workplaces compared to the 0800 and 1000 hr data. Only the Boiler house, Upper pan floor and P_5 had significantly different thermal loads from that of stream A evaporators. Stream B and the Lower pan floor thermal loads were also significantly different from that of the Boiler house.

For the 1400 hr data, only the E_{A1} workplace had a thermal load that was from that of the Boiler house, Upper pan floor and P_5 workplaces. The 1600 hr data registered a significant difference only between the E_{A1} workplace and the Boiler house and Upper pan floor workplaces. Significant differences for the 2000 hr data were noted only between the boiler house workplace and the Upper pan floor workplace. This was a result of the general drop in the temperatures for the night time readings.

With the exception of the differences between the stream A evaporators and the Boiler house, and between P_{11} and B_{1B}, all the other workplaces had non-significant thermal load differences for the 2200 hr data. As the temperature continued to drop, less significant differences were registered. At 2400 hr. there was a significant difference between the upper pan floor and the Boiler house (B_{1B} specifically) workplace. Also a significant difference was noted between the E_{A1} and the Boiler house workplaces. For the 0200 hr data, there was a significant difference between the thermal loads existing at the stream A evaporators and the Boiler house workplaces still attributed to the decreasing temperatures. A further significant difference was noted between E_{A1} and E_{B2}. A similar trend to that at 0200 hr was observed for the 0400 hr data.

4.2 Dust Sampling

4.2.1 Results of the sampling

Data obtained for the dust samples is presented in Table 4.13. The table includes measurements taken prior to sampling as well as those taken after sampling, both of which were required for the determination of dust concentration. The data included personal samples and fixed position or background samples.

4.2.2 Analysis of data

a) <u>Theoretical analysis</u>

On a routine basis, the examination of dust samples is concerned with determination of concentration. The dust weight was obtained by weighing the filter before and after sampling. The concentration was then determined using equation (2.14) of Section 2.10.3. The results of the computations are presented in Table 4.13.

Table 4.13: Dust sampling results

Sampling position	Filter No.	Weight of filter mg	Weight of filter and dust mg	Weight gain mg	Dust concentration $mg\ m^{-3}$	Mean dust concentration $mg\ m^{-3}$
Personal samples	D39/97 D41/97	22.780 20.970	22.840 21.100	0.060 0.130	1.250 2.708	1.979
Bagasse store Platform	D27/97 D34/97	16.526 12.443	16.773 13.585	0.247 1.142	1.029 4.758	2.894
Outside Bagasse tower	D28/97 D38/97	19.012 23.730	19.451 25.100	0.439 2.630	1.829 10.958	6.394
Outside the foundry	D30/97 D35/97	14.990 20.000	15.171 20.510	0.181 0.510	0.754 2.125	1.440
Btn Boiler h'se and W/shop	D33/97 D36/97	16.684 23.770	16.983 24.790	0.299 1.020	1.246 4.250	2.748
Boiler h'se B12	D37/97 D40/97	25.000 24.790	25.550 24.930	0.550 0.140	2.292 0.583	1.438
Boiler h'se B34	D26/97 D31/97	14.932 13.423	15.818 13.458	1.086 0.035	4.525 0.146	2.270

b) Statistical analysis

The least significant difference (lsd) criterion was used to analyze the difference between the dust concentration means for the different sampling positions. The criterion involved the computation of the smallest difference which was declared significant and the absolute value of each was compared with it. The lsd was calculated at a 5 and 1% level of significance. The means of the dust concentration were ranked from smallest to largest and the differences are presented in Table 4.14.

For $t_{(0.025)} = 12.706$ and $r = 2$, the least significant difference is given as:

$lsd(0.05) = 12.706\sqrt{(2 \times 2.927)/2}$

$= 21.737$

For $t_{(0.005)} = 6.314$, the lsd = 10.802

Table 4.14: Differences between dust concentration means

	1.440	1.979	2.270	2.748	2.894	6.394
1.438	0.002	0.541	0.832	1.310	1.456	4.956
1.440		0.539	0.830	1.308	1.454	4.954
1.979			0.291	0.769	0.915	4.415
2.270				0.478	0.624	4.124
2.748					0.146	3.646
2.894						3.500

4.2.3 Discussion of results

Since selective sampling instruments (gravimetric) were used for sampling, specific portions of dust were obtained. Only the respirable was collected in the case of personal sampling and the total inhalable portion in the case of fixed position sampling. Results of dust concentration indicated a potential hazard to the bagasse store attendants (exposure limit: less than 0.1 mg m^{-3}). As Literature revealed, when dry, bagasse is rapidly broken down into dust and the inhalation of dried bagasse dust may cause a disease of the respiratory system called "Bagassosis".

Analysis of the fixed position samples indicated a potential hazard for the bagasse tower surroundings. For the other sampled workplaces, the results were within the "accepted" range (0.1 - 4 mg m^{-3}) for normal working conditions for healthy individuals, on the basis of a working life of 30 to 35 years. Furthermore, the unsafe acts of the workers rendered the workplaces more hazardous. Safety wear for the nose and eyes is provided by the management, but rarely do the workers adhere to the workplace regulations.

From the statistical analysis it is evident that the observed differences all lie below 10.802, so they are not significant at 1% nor 5%. This implies that for the sampling positions under study, the mean dust concentrations did not differ greatly.

4.3 Subjective response

4.3.1 Results of the survey

Data for the subjective response was obtained from the safety committee, company clinic and the operators in the Process house, Boiler house and Bagasse store attendants. The data obtained from the questionnaires was coded for analysis using the information given in the original questionnaire as a guide to the coding procedure. The coded questionnaire is presented in Appendix A2.

4.3.2 Analysis of the questionnaires

The analysis of the completed questionnaires was computer based using the SPSS analysis package. Two stages in the analysis were required: first the data was edited to identify any inconsistencies in the responses to the questions and secondly the data was tabulated. The data entered into the computer (termed 'raw' data) was edited to remove logical errors to generate the 'treated' data. It was the treated data on which the analysis was performed. The frequencies and percentages of the responses obtained from the SPSS analysis are presented in Table 4.15 for the different departments sampled.

4.3.3 Discussion of results

The objective of the maintenance/safety department section was to verify the existence of a health and safety policy in the company and an insurance for the company's undertakings. The questionnaire survey revealed that despite the existence of work rules and regulations pertaining to occupational health and safety, the company lacked a clear, well defined health and safety policy.

With the ongoing diffuser project, safety awareness has become an issue of utter importance to the company and, the major roles played by the safety committee include the regular safety inspection of workplaces and sensitizing workers on the management of safety and health mainly through health and safety campaigns.

Of recent the company has introduced occupational health and safety training targeted for all the workers on an annual basis. Previously this was not the case due to the lack of a clear safety policy. Unfortunately, majority of the safety committee members (85.71%) were not aware of the existence of an industrial insurance for the company's undertakings and hardly did they monitor the actual degree of risks in the company.

Table 4.15: SPSS results of the questionnaire analysis

Question	Value	Freq.	Percent
Q1: M	1	32	100.00
F	2		
Q2	0.58	1	3.13
	0.67	1	3.13
	5.00	1	3.13
	6.00	1	3.13
	7.00	1	3.13
	8.00	1	3.13
	10.00	4	12.50
	11.00	1	3.13
	12.00	1	3.13
	13.00	1	3.13
	14.00	2	6.25
	15.00	3	9.38
	16.00	1	3.13
	18.00	4	12.50
	19.00	1	3.13
	20.00	3	9.38
	21.00	1	3.13
	22.00	1	3.13
	23.00	1	3.13
	24.00	2	6.25

Table 4.15: Cont'd

Q3: Y	1	7	100.00
N	2		
Q4: a	1	7	100.00
b	2	–	–
c	3	1	14.29
d	4	–	–
e	5	1	14.29
Q5: a	1	7	100.00
b	2	–	–
c	3	2	28.57
d	4	2	28.57
e	5	1	14.29
f	6		
Q6: Y	1	–	–
N	2		
Q7: a	1	2	28.57
b	2	3	48.86
c	3	2	28.57
d	4	1	14.29
Q8: a	1	4	57.14
b	2	6	85.71
c	3	4	57.14
d	4	5	71.43
e	5		
Q9: a	1	–	–
b	2	3	42.86
c	3	5	71.43
d	4	3	42.86
Q10: Y	1	6	85.71
N	2	1	14.29
Q11: a	1	2	28.57
b	2	1	14.29
c	3	2	28.57
Q12: a	1	–	–
b	2	–	–
c	3	–	–
d	4	1	14.29
Q13: Y	1	1	14.29
N	2	6	85.71
Q14: a	1	4	57.14
b	2	–	–
c	3	1	14.29
d	4	2	28.57

Table 4.15: Cont'd

Q15: a	1	1	33.33
b	2	1	33.33
c	3	3	100.00
d	4		
Q16: a	1	2	66.67
b	2	1	33.33
c	3	2	66.67
d	4	1	33.33
e	5	1	33.33
f	6		
Q17: Y	1	3	100.00
N	2		
Q18: a	1	1	33.33
b	2	–	–
c	3	2	66.67
Q19: a	1	2	66.67
b	2	–	–
c	3	2	66.67
d	4	–	–
e	5		
Q20: Y	1	2	66.67
N	2	1	33.33
Q21: a	1	1	33.33
b	2	2	66.67
c	3	2	66.67
d	4	3	100.00
e	5	2	66.67
Q22: a	1	1	33.33
b	2	1	33.33
c	3	–	–
d	4	–	–
e	5		
Q23: a	1	1	4.55
b	2	7	31.82
c	3	18	81.82
d	4	10	45.45
e	5	4	18.18
f	6		
Q24: Y	1	16	72.73
N	2	6	27.27
Q25: a	1	1	4.55
b	2	2	9.09
c	3	9	40.91
d	4	5	22.73

Table 4.15: Cont'd

Q26: a	1	1	4.55
b	2	9	40.91
c	3	5	22.73
d	4	2	9.09
e	5	1	4.55
Q27: a	1	3	13.64
b	2	4	18.18
c	3	5	22.73
Q28: Y	1	16	72.73
N	2	6	27.27
Q29: a	1	4	18.18
b	2	16	72.73
c	3	10	45.45
d	4	1	4.55
Q30: Y	1	16	72.73
N	2	5	22.73
Q31: a	1	4	18.18
b	2	6	27.27
c	3	14	63.64
d	4	9	40.91
e	5	2	9.09
Q32: a	1	3	13.64
b	2	2	9.09
Q33: a	1	17	77.27
b	2	15	68.18
c	3	14	63.64
d	4	7	31.82
e	5		

The objective of the company clinic section was to establish the risk, damage or accident statistics. Physical statistics could not be accessed as this is classified data for the company. However, the survey revealed that the non-observance of health and safety rules and regulations was at the root cause of most accidents. No risk and damage statistics were complied in the company. The company has an employees' insurance policy against occupational related accidents and diseases and, an accident form must be completed within 24 hr from the occurrence of an accident.

However, the insurance has not been very effective since it does not carry out plant health and safety audits and risk assessments. Workers are never examined to verify their health status during their stay on the job besides the first examination prior to employment. The clinical officers indicated a need to emphasize health and safety at all times in all workplaces. The major roles they played in insuring workers' health and safety included providing medical treatment and, compiling and periodically reviewing accident statistics.

The establishment of the workers' subjective judgement of their working environment was the main objective of the factory workers section. As much as health and safety rules exist, most workers (81.82%) indicated a need for emphasizing and improving the safety in their workplaces. Some safety wear (ear muffs, eye goggles, nose protectors, safety boots) is provided by the management, but workers rarely conform to the safety regulations. Unfortunately, non-observance of these rules at most earns workers some disciplinary action, but sometimes one could go without any penalty paid. Management has however continued to provide induction training for all the workers in every department.

The major hazard that the sampled workplaces presented to the workers was a deteriorating health with the main complaint being ear-nose and throat (ENT) problems, eyes problems and physical fatigue. In promoting health and safety in their respective departments, most workers take action on health and safety problems as well as preventive activities.

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

5.1.1 Thermal environment

Following the results and discussion on the thermal environment in the working environment studied at MSC, the following conclusions can be drawn:

a) The four environmental components measured in the study sites were outside the recommended ranges of exposure especially between 1200 and 1600 hr so as to cause physiological problems of dehydration and physical fatigue, with the evaporators workplace in the Process house being the most affected than the others owing to the relative orientation of the evaporators and the heaters, and the worn out insulation of the vessels. The exhaust steam from the evaporators and the vacuum pans was the major cause of the hot working environment. A possible decline in the work rate or productivity of exposed workers is likely to occur as a result of these uncomfortable working conditions.

b) A combination of the four parameters still produced greater thermal loads in the Process house than the Boiler house with the stream A evaporators having significantly different thermal loads from the rest of the sampled workplaces. The workers in this workplace therefore operated in stressful thermal conditions due to their proximity to the heat source combined with the lack of proper safety thermal wear and, were most prone to physiological problems of physical fatigue, weak limbs and dehydration.

5.1.2 Dust sampling

The following conclusions can be drawn following the analysis and discussion of the dust sampling results:

a) Although the differences between the mean dust concentrations were all not significant different at 1 and 5%, the personal sampling concentration far exceeded the recommended exposure limits and the workers in the bagasse store were prone to physiological effects of chest problems, ENT and eyes problems owing to continued exposure. As the questionnaire survey revealed, the bagasse store attendants had more ENT and eyes problems than the other workers.

b) Concentrations of the fixed position sampling were bearable for health individuals not exceeding 35 years working under the same environment. Since workers are never periodically examined to verify their health status unless a need arises, the judgement of healthy individuals would be purely subjective.

5.1.3 Subjective response

From the questionnaire survey, the following conclusions can be drawn:

a) The lack of clear, well defined occupational health and safety policy at Mumias Sugar Company was the root cause of the slow health and safety process at workplaces.

b) As evident from the accidents statistics, accidents in at Mumias Sugar Company (factory department) were caused more by the unsafe acts of workers than the unsafe working conditions.

A subjective judgement of the workplace indicated a general health deterioration of the exposed personnel with the major physiological effects of chest, eyes and ENT problems.

5.2 Recommendations

5.2.1 Thermal environment

It is not easy to define a working environment that will be comfortable to all the workers in a particular workplace owing to the variations in the physical characteristics of different persons, and the best that can be achieved, is to provide conditions which will be agreeable to the greatest number. However, from the conclusions drawn for the thermal environment existing at MSC, the following recommendations can be made:

a) Since natural ventilation has not proved quite adequate, forced ventilation should be considered in the workplaces studied with the aim of maintaining the air temperature within the recommended design envelop of 25 and 27°C with a relative humidity of 20 and 60% to increase the cooling effect.

b) The effects of radiant heat may be reduced by placing barriers between its source and the workers. These barriers may take the form of: i) renewing the layers of insulation over heat loss; ii) reflectant shields, which, to be effective, must be highly polished and maintained in a state of cleanliness; iii) absorbent shields, which can be prevented from becoming sources of heat by being especially cooled with air or water; or iv) personal protective garments (heat protective clothing) which provide a layer of insulation over the wearer and if coated with aluminium, the surface will reflect infrared radiation.

c) Further research based on a detailed physiological assessment of each particular job should be carried out to determine the durations of exposure and rest periods where it is impossible to exercise control over the source of thermal stress so as to limit the exposure to these uncontrolled conditions by the introduction of working schedules (time - limited exposure schedules). When working conditions are severe, minor differences between one industrial situation and another in terms of work rate, type of protective clothing, the radiant heat loads and the physical characteristics of the workers can have a dramatic effect on the physiological response.

d) A work study should also be carried out to ascertain job inefficiency resulting from these uncomfortably warm workplaces.

5.2.2 Dust sampling

Considering both the personal sampling and fixed position samples, the following recommendations could assist the management of MSC and other sugar industries to address the bagasse issue:

a) Storage of bagasse in a bin silo with a special design for moving bagasse in and out would limit the direct handling of bagasse by workers hence minimizing the physiological effects associated with this exposure as opposed to the open store handling existing at MSC at the moment.

b) Densifying of bagasse would reduce the requirement for storage volume.

c) To control the spillage of bagasse from the conveyors when moving it to the boilers or from the mills, either all the conveyors should be properly enclosed or a pneumatic system could be introduced in place of the conveyors.

d) The bagasse can also be passed though rotatory sieves to remove the fine particles (bagassilo) which can be used as a filter aid later in the process.

e) Further research should be carried out to explore the economics (cost vis-à-vis benefits) of wetting the bagasse during its disposal, by the use of sprinklers at the point of exit for the mills, to prevent the bagassilo particles from becoming airborne.

5.2.3 Subjective response

In order to promote a safe working environment, the following recommendations should be considered by the company:

a) A general occupational health and safety policy must be defined on which all particular policy making should be based.

b) Increased training and awareness to encourage the use of personal protective devices, easy identification of hazard signals by properly planned programmes, display posters and, screening videos.

c) A spirit of teamwork and co-operation should be generated among all the workers with the goal of a higher safety level. Joint efforts involving all employees are necessary in order to achieve a general state of health and safety.

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APPENDIX A

This Appendix contains both the original questionnaire and the coded questionnaire used in SPSS the analysis

Appendix A1: **QUESTIONNAIRE**

General

Sex **M** [ ] **F** [ ]

For how long have you worked with this company?

Maintenance/safety department

1. Do you have work rules and regulations pertaining to occupational safety?

   Y [ ] **N** [ ]

   If N, go to **4** else

2. Who enforces these rules?
   - **a)** entire management
   - **b)** production manager
   - **c)** section head or foreman
   - **d)** all workers
   - **e)** any other, specify

3. How do you ensure that all workers observe these rules?
   - **a)** through safety campaigns
   - **b)** through safety awards
   - **c)** through close supervision of workers
   - **d)** through penalty for bad record employment
   - **e)** any other, specify
   - **f)** none, specify

4. Do you consider incorporating these rules?

Y [ ] N [ ]

5. What are your views about occupational safety?

6. What role does the department play in ensuring the safety of other workers?

a) investigate potential hazards

b) make regular safety inspections at workplaces

c) promote cooperation of all workers in the safety and health efforts

d) educate workers and sensitize them on the management's safety and health rules

e) any other, specify

7. How is safety promoted in this company?

8. Do you offer any training on occupational health and safety?

Y [ ] N [ ]

9. If Y, how often is this done?

10. If N, what hinders the training?

11. Does industrial insurance for undertakings exist in this company?

Y [ ] N [ ]

12. How often do you monitor the actual degree of risk and what measures, if any, do you employ?

Company clinic

1. What is your view about occupational health and safety?

2. What role(s) do you play in ensuring workers safety and health?
    a) provide medical treatment for injured workers, examination and health counseling
    b) take part in preventive activities (specify)
    c) compile and periodically review health statistics
    d) provide guidance and supervise workers' health and working environment
    e) advise management and workers' representatives on working environment and ergonomics
    f) any other, specify.

3. Does the company have an employees' insurance policy against occupational related accidents and diseases?

    Y [ ]   N[ ]

4. How useful has this insurance been in maintaining workers' safety and health at workplaces? Explain.

5. How often are employees examined to verify their health status?

6. Do you hold risk, damage or accident statistics?

    Y [ ]   N [ ]

7. What are the causes of these accidents?
    a) lack of machinery guarding
    b) lack of personal protective equipment
    c) lack of safe system of work

d) non-observance of safety rules and regulations

e) any other, specify

f) none, specify

8. If N, why?

a) because none gets reported

b) because no one compiles the statistics

c) it is not important

d) any other reason, specify

e) none, specify

Factory workers

1. What are your views about safe working conditions?

2. Do you have work rules for carrying out your job in a safe manner?

Y [ ] N [ ]

3. If Y, who ensures the observance of these rules in your department?

a) departmental manager

b) foreman

c) special committee

d) all departmental workers

4. And what penalty do you have to pay for non-observance of rules?

5. If N, do you consider these rules necessary? Explain

6. Do you receive any induction training in your department?

Y [ ] N [ ]

7. Do your working conditions pose any problems in the way you carry out your job? Explain.

8. Have work conditions had any health effects on you?

Y [ ] **N** [ ]

9. If Y, explain in relation to your specific working condition (hot working conditions or dusty environment).

10. If **N**, do you consider your workplace safe? Explain

11. What role(s) do you play in promoting safe working conditions in your department?

   - **a)** take action on safety and health problems
   - **b)** take part in preventive activities (specify)
   - **c)** promote cooperation among fellow workers in safety and health efforts
   - **d)** any other, specify
   - **e)** none, specify.

Appendix A2: **CODED QUESTIONNAIRE**

General

1. Sex: **M [ ]** **F [ ]**

1 *2*

2. For how long have you worked with this company?

Maintenance/safety department

3. Do you have work rules and regulations pertaining to occupational safety?

Y [ ] **N [ ]**

1 *2*

If **N**, go to 4 else

4. Who enforces these rules?

1 **a)** entire management

2 **b)** production manager

3 **c)** section head or foreman

4 **d)** all workers

5 **e)** any other, specify

5. How do you ensure that all workers observe these rules?

1 **a)** through safety campaigns

2 **b)** through safety awards

3 **c)** through close supervision of workers

4 **d)** through penalty for bad record employment

5 **e)** any other, specify

6 **f)** none, specify

6. Do you consider incorporating these rules?

Y[ ]   N[ ]

1   *2*

7. What are your views about occupational safety?

1 a) requires awareness

2 b) It's of utter importance

3 c) should be emphasized in all establishments

4 d) none, specify

8. What role does the department play in ensuring the safety of other workers?

1 a) investigate potential hazards

2 b) make regular safety inspections at workplaces

3 c) promote cooperation of all workers in the safety and health efforts

4 d) educate workers and sensitize them on the management's safety and health rules

5 e) any other, specify

9. How is safety promoted in this company?

1 a) through conferences

2 b) through safety & health committee

3 c) through campaigns

4 d) through seminars

10. Do you offer any training on occupational health and safety?

Y[ ]   N[ ]

1   *2*

11. If **Y**, how often is this done?

1 a) annually   *2* b) twice a year   *3* c) seldom

12. If **N**, what hinders the training?

1 a) cost involved
2 b) manpower
3 c) not necessary
4 d) none, specify

13. Does industrial insurance for undertakings exist in this company?

Y[ ] N[ ]

1 2

14. How often do you monitor the actual degree of risk and what measures, if any, do you employ?

1 a) never
2 b) rarely
3 c) annually
4 d) none, specify

Company clinic

15. What is your view about occupational health and safety?

1 a) requires awareness
2 b) Is of utter importance
3 c) should be emphasized
4 d) none, specify

16. What role(s) do you play in ensuring workers safety and health?

1 a) provide medical treatment for injured workers, examination and health counseling
2 b) take part in preventive activities (specify)
3 c) compile and periodically review health statistics
4 d) provide guidance and supervise workers' health and working environment
5 e) advise management and workers' representatives on working environment and ergonomics
6 f) any other, specify.

17. Does the company have an employees' insurance policy against occupational related accidents and diseases?

Y[ ] N[ ]

1 *2*

18. How useful has this insurance been in maintaining workers' safety and health at workplaces? Explain.

1 **a)** not effective/limited *3* **c)** none, specify

2 **b)** quite effective

19. How often are employees examined to verify their health status?

1 **a)** once, prior to employment *3* **c)** as need arises

2 **b)** periodically, specify *4* **d)** never

5 **e)** none, specify

20. Do you hold risk, damage or accident statistics?

Y[ ] N[ ]

1 *2*

21. What are the causes of these accidents?

1 **a)** lack of machinery guarding

2 **b)** lack of personal protective equipment

3 **c)** lack of safe system of work

5 **d)** non-observance of safety rules and regulations

6 **e)** any other, specify

7 **f)** none, specify

22. If N, why?

1 **a)** because none gets reported

2 **b)** because no one compiles the statistics

3 c) it is not important

4 d) any other reason, specify

5 e) none, specify.

Factory workers

23. What are your views about safe working conditions?

1 a) should be everyone's goal *2* b) safety wear should be provided

3 c) safety should be emphasized/improved

4 d) safety should be of utter importance to management

5 e) any other, specify *6* f) none, specify

24. Do you have work rules for carrying out your job in a safe manner?

Y [ ] N [ ]

1 *2*

25. If Y, who ensures the observance of these rules in your department?

1 a) departmental manager *3* c) special committee

2 b) foreman *4* d) all departmental workers

26. And what penalty do you have to pay for non-observance of rules?

1 a) suspension *3* c) no penalty

2 b) face disciplinary action *4* d) reduced premium/incentives

5 e) none, specify

27. If N, do you consider these rules necessary? Explain. Y because

1 a) they will improve working conditions

2 **b)** they will control the unsafe acts of workers

3 **c)** they will be a remainder of our role(s) towards safety

28. Do you receive any induction training in your department?

Y [ ] **N** [ ]

1 *2*

29. Do your working conditions pose any problems in the way you carry out your job?

Explain. **Y**, because they:

1 **a)** reduce output due to harsh conditions

2 **b)** cause health deterioration

3 **c)** present high accident potential

4 **d)** any other, specify

30. Have work conditions had any health effects on you?

Y [ ] **N** [ ]

1 *2*

31. If Y, explain in relation to your specific working condition (hot working conditions or dusty environment).

1 **a)** dehydration

2 **b)** chest problems

3 **c)** ENT and/or eyes problems

4 **d)** weak limbs(physical fatigue)

5 **e)** any other, specify

32. If **N**, do you consider your workplace safe? Explain. **N**

1 **a)** because of poor safety wear

2 **b)** because of poor disposal methods of bagasse

33. What role(s) do you play in promoting safe working conditions in your department?

1 **a)** take action on safety and health problems

2 **b)** take part in preventive activities (specify)

3 **c)** promote cooperation among fellow workers in safety and health efforts

4 **d)** any other, specify

5 **e)** none, specify.

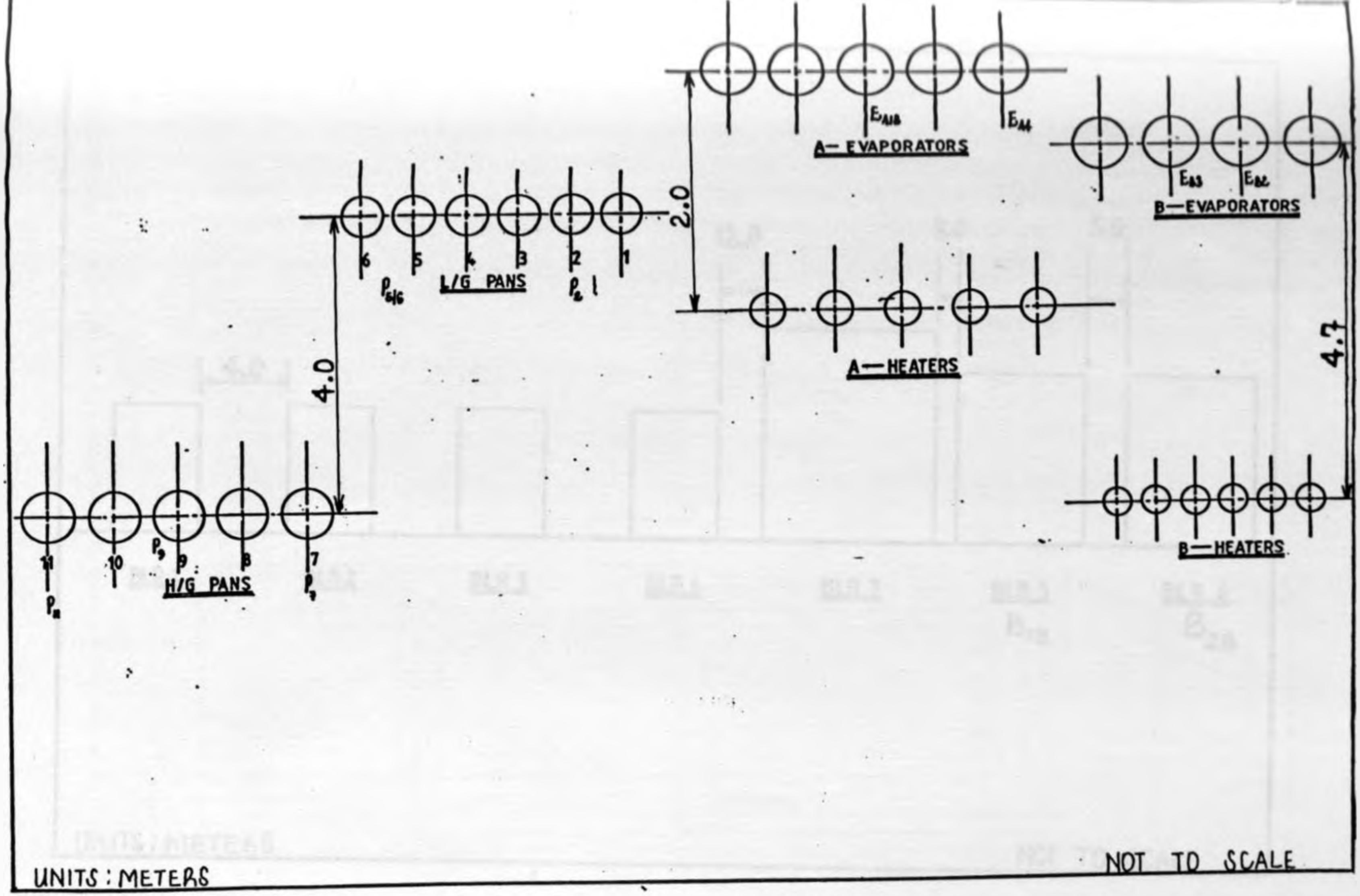
APPENDIX B

This Appendix shows the Layout of the three study sites chosen in the Factory Department.

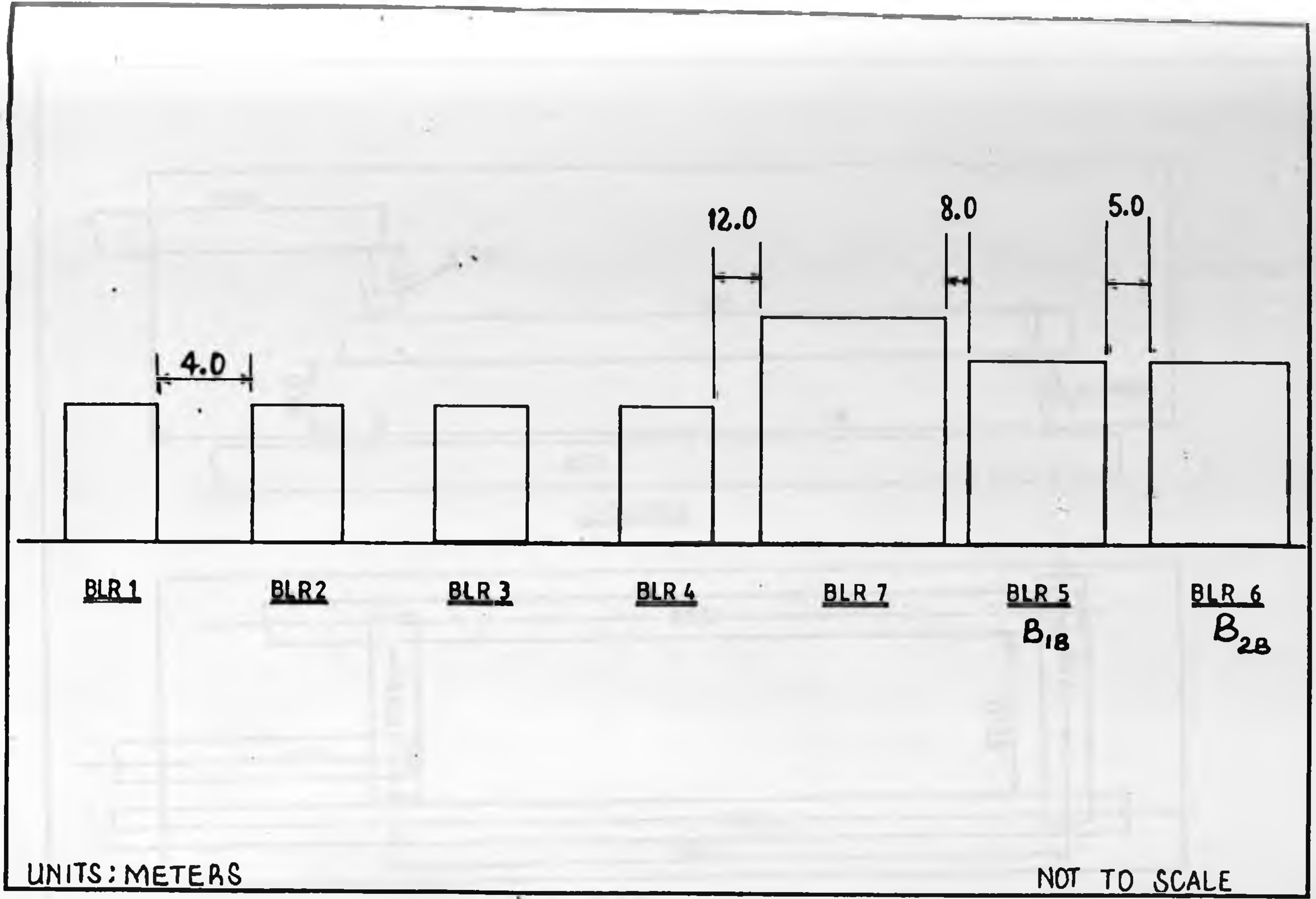
Appendix B1: Process House

Appendix B2: Boiler House

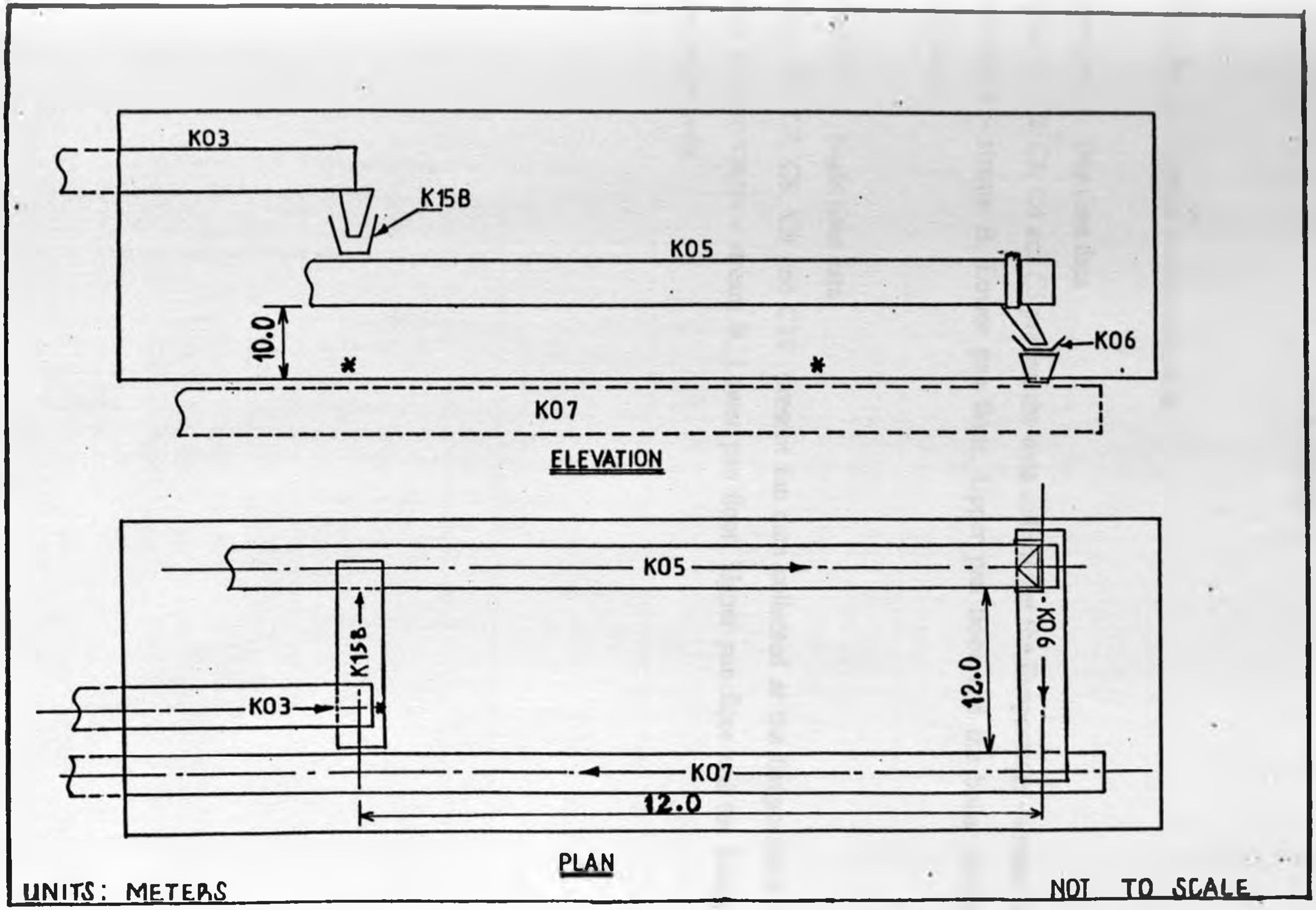
Appendix B3: Bagasse Store



PROCESS HOUSE SKETCH: PLAN



BOILER HOUSE SKETCH: ELEVATION



BAGASSE STORE SKETCH

APPENDIX C

The collected Thermal environment data

Appendix C1: Day time data

Tables C1, C2, C3, C4 and C5 present the data collected at the Evaporators - stream A Evaporators - stream B, Lower pan floor, Upper pan floor and the boiler house respectively.

Appendix C2: Night time data

Tables C6, C7, C8, C9 and C10 present the data collected at the Evaporators - stream A Evaporators - stream B, Lower pan floor, Upper pan floor and the boiler house respectively.

Appendix C1: Day Time Data

Table C1: Evaporators A-stream

Time	t_a (°C)		t_r (°C)		v (m/s)		rh (%)	
0800	E_{A1}	E_{A4}	E_{A1}	E_{A4}	E_{A1}	E_{A4}	E_{A1}	E_{A4}
	32.2	30.6	42.0	35.0	0.01	0.32	57	54
	33.4	32.8	42.5	42.0	0.01	0.02	55	58
	33.7	30.5	43.0	35.5	0.59	0.09	54	54
	32.0	30.5	41.5	35.0	0.20	0.04	54	56
Mean	32.8	31.1	42.3	36.9	0.25	0.12	55	56
1000	37.4	36.1	46.0	40.0	0.02	0.17	38	42
	37.0	35.8	46.0	38.5	0.34	0.40	46	45
	37.8	36.0	45.5	39.5	0.30	0.33	36	33
	37.2	36.7	46.5	40.5	0.10	0.26	46	37
Mean	37.4	36.2	46.0	39.6	0.19	0.29	42	39
1200	40.2	38.9	48.0	42.0	0.20	0.15	20	30
	39.8	38.9	48.5	42.5	0.12	0.18	25	26
	38.5	37.0	47.0	41.5	0.08	0.04	30	28
	40.4	39.5	48.0	43.0	0.09	0.24	27	25
Mean	39.7	38.6	47.9	42.3	0.25	0.15	26	27
1400	40.1	39.0	51.0	45.0	0.57	0.20	20	21
	43.6	40.1	52.5	45.5	0.46	0.40	23	22
	42.1	42.0	51.5	46.0	0.30	0.20	22	23
	44.3	43.0	53.5	47.5	0.15	0.19	23	20
Mean	42.5	41.0	52.1	46.0	0.37	0.25	22	22
1600	41.9	41.6	51.0	46.0	0.80	0.01	31	32
	42.2	41.6	52.0	46.5	0.50	0.47	34	22
	43.5	39.8	53.5	44.5	1.08	0.18	27	30
	40.8	39.5	49.0	44.5	1.03	1.09	35	34
Mean	42.1	40.6	51.4	45.4	0.85	0.44	32	30

Table C2: Evaporators B-stream

Time	t_a (°C)		t_r (°C)		v (m/s)		rh (%)	
0800	E_{B2}	E_{B3}	E_{B2}	E_{B3}	E_{B2}	E_{B3}	E_{B2}	E_{B3}
	31.4	31.0	34.0	34.5	0.54	0.60	52	50
	30.6	30.7	33.5	33.0	0.25	0.39	58	58
	27.8	29.2	32.0	32.5	0.20	0.36	51	50
	26.7	29.0	31.3	32.5	0.25	0.31	57	57
Mean	29.1	30.0	32.8	33.1	0.31	0.42	55	54
1000	36.2	63.4	39.0	39.0	0.39	0.31	35	39
	35.2	35.7	37.5	38.5	0.59	0.41	45	44
	33.9	35.2	38.5	38.5	0.83	0.84	30	31
	32.1	33.0	36.0	36.5	1.21	1.22	37	36
Mean	34.4	35.1	37.8	38.1	0.76	0.70	37	38
1200	38.0	38.7	43.0	43.0	0.50	0.52	35	39
	36.7	37.6	42.0	42.0	1.20	0.24	32	33
	38.7	38.9	43.5	43.5	0.66	0.55	34	30
	37.0	38.5	42.0	43.0	1.03	0.40	25	25
Mean	37.6	38.4	42.6	42.9	0.85	0.43	32	32
1400	39.5	39.0	45.0	45.0	0.62	0.32	21	20
	39.9	38.9	45.5	44.0	0.48	0.16	38	35
	41.1	41.7	46.0	46.5	0.47	0.59	25	21
	39.3	40.4	44.5	45.5	0.43	0.24	23	24
Mean	40.0	40.0	45.3	45.3	0.50	0.33	27	25
1600	41.7	42.0	46.0	46.0	0.93	0.76	31	31
	40.7	41.0	45.5	45.0	0.96	0.45	30	32
	36.9	38.6	43.5	44.5	0.62	0.62	28	30
	38.1	38.4	44.0	44.5	1.10	1.55	34	36
Mean	39.4	40.0	44.8	45.0	0.90	0.84	31	32

Table C3: Vacuum pans - Lower floor

Time	t_a (°C)		t_r (°C)		v (m/s)		rh (%)	
0800	P_2	P_5	P_2	P_5	P_2	P_5	P_2	P_5
	30.3	27.8	32.0	33.0	0.25	0.15	49	46
	30.0	29.3	32.5	33.5	0.30	0.36	48	46
	31.4	28.3	33.0	32.5	0.37	0.31	47	42
	27.7	27.5	31.0	33.0	0.53	0.47	49	46
Mean	29.9	28.2	32.1	33.0	0.36	0.32	48	45
1000	35.2	33.2	37.0	35.5	0.29	0.08	32	30
	34.0	32.0	36.0	34.0	0.34	0.23	37	34
	34.3	32.9	36.5	34.5	0.50	0.25	36	35
	34.5	33.9	37.0	36.5	0.32	0.20	41	33
Mean	34.5	33.0	36.6	35.1	0.36	0.19	37	33
1200	38.2	36.4	42.5	41.5	0.17	0.15	35	37
	36.6	34.5	41.5	39.5	0.36	0.47	24	28
	38.6	38.4	42.5	41.0	0.20	0.18	22	20
	36.6	35.7	41.0	40.0	0.32	0.20	26	22
Mean	37.5	36.3	41.9	40.8	0.26	0.25	27	27
1400	39.1	37.0	44.0	40.0	0.22	0.24	25	25
	43.5	42.8	45.5	44.0	0.17	1.30	32	35
	39.3	38.9	44.0	40.0	0.25	0.48	21	22
	40.5	39.3	44.0	42.0	0.21	0.51	22	22
Mean	40.6	39.5	44.4	41.6	0.21	0.63	25	26
1600	39.5	37.6	42.0	43.5	0.88	0.98	33	34
	40.2	38.0	42.5	42.5	0.80	0.75	26	22
	42.5	40.8	44.5	43.5	0.58	1.23	29	33
	41.1	39.6	43.0	43.0	0.59	1.18	35	37
Mean	40.8	39.0	43.0	43.1	0.71	1.04	31	32

Table C4: Vacuum pans - upper floor

Time	t_a (°C)			t_r (°C)			v (m/s)			rh (%)		
0800	P_7	P_9	P_{11}	P_7	P_9	P_{11}	P_7	P_9	P_{11}	P_7	P_9	P_{11}
	26.7	26.2	25.2	31.0	30.0	31.0	0.50	0.13	0.13	57	54	50
	28.8	27.5	27.9	32.0	31.0	33.0	0.48	0.45	0.29	43	46	56
	28.2	27.3	27.0	30.0	31.0	31.5	0.93	0.34	0.41	58	57	45
	28.8	28.0	27.9	32.5	31.5	32.5	0.51	0.46	0.28	42	46	57
Mean	28.1	27.3	27.0	31.4	30.9	32.0	0.61	0.36	0.28	50	51	52
1000	31.0	29.7	28.9	37.5	37.5	37.0	0.10	0.22	0.39	39	32	30
	31.3	31.1	30.1	37.5	38.5	36.0	0.20	0.04	0.08	38	34	31
	33.9	31.8	31.4	39.0	38.5	37.5	0.42	0.43	0.56	35	30	25
	33.6	32.3	31.5	39.5	39.0	37.5	0.24	0.22	0.08	40	36	33
Mean	32.5	31.2	30.5	38.4	38.4	37.0	0.24	0.23	0.28	38	33	30
1200	34.4	33.8	34.3	40.0	40.5	40.0	0.10	0.66	0.26	29	29	31
	33.7	33.9	33.6	40.0	40.0	40.0	0.50	0.35	0.16	27	22	25
	37.7	35.2	35.3	42.5	39.0	39.5	1.55	0.94	0.56	28	27	30
	36.6	36.9	37.2	41.0	40.0	41.5	0.35	0.68	0.83	30	31	29
Mean	35.6	35.0	35.1	40.9	39.9	40.3	0.63	0.66	0.45	29	27	29
1400	35.4	35.4	34.5	43.0	41.0	42.0	0.25	0.70	0.31	24	22	20
	39.8	39.6	37.3	43.5	42.0	42.5	1.04	0.92	0.77	27	25	30
	40.1	39.7	37.6	44.0	42.5	42.0	0.59	0.93	0.43	37	34	39
	39.3	38.3	38.6	43.0	42.0	42.0	0.63	0.72	0.32	25	23	21
Mean	38.7	38.3	37.0	43.4	41.9	42.1	0.63	0.82	0.46	28	26	28
1600	36.2	36.0	35.5	42.0	42.0	44.0	2.04	0.65	0.47	36	34	33
	36.7	36.3	36.5	41.5	42.0	44.5	1.83	0.84	0.42	38	36	38
	39.8	39.0	38.5	43.5	43.5	43.0	0.79	0.83	0.47	35	36	38
	38.4	39.0	39.2	41.5	43.0	44.5	1.06	0.71	0.52	38	34	35
Mean	37.8	37.7	37.4	42.1	42.6	44.0	1.43	0.76	0.47	37	35	37

Table C5: Boiler house

Time	t_a (°C)		t_r (°C)		v (m/s)		rh(%)	
0800	1B	2B	1B	2B	1B	2B	1B	2B
	26.2	27.6	31.5	20.0	0.37	0.56	51	53
	24.6	25.3	31.0	27.5	0.33	0.47	56	54
	23.4	23.8	30.5	24.0	0.26	0.42	56	57
	28.7	27.0	30.5	35.0	0.40	0.55	66	61
Mean	25.8	25.9	30.9	28.4	0.34	0.50	57	56
1000	33.6	31.1	36.5	35.0	0.20	0.31	29	28
	29.2	29.1	35.5	32.0	0.31	0.23	44	43
	26.2	26.5	35.0	27.5	0.28	0.19	46	46
	33.5	33.7	36.0	41.5	0.35	0.28	29	30
Mean	30.6	30.1	35.8	34.0	0.29	0.25	37	37
1200	34.7	35.3	38.0	37.5	0.52	0.73	24	24
	32.6	32.3	40.5	36.5	0.37	0.41	26	29
	29.3	29.8	40.0	31.5	0.51	0.32	42	44
	35.5	36.6	39.0	43.0	0.48	0.50	30	29
Mean	33.0	33.5	39.4	37.1	0.47	0.49	31	32
1400	36.9	37.1	39.5	39.0	0.48	0.62	22	23
	36.4	37.1	42.5	39.5	0.09	0.33	24	26
	36.1	36.6	41.0	38.5	0.42	0.61	38	36
	39.1	39.3	40.5	43.5	0.38	0.52	25	21
Mean	37.1	37.5	40.9	40.1	0.34	0.52	27	27
1600	29.4	30.4	33.5	40.0	0.39	1.09	38	39
	37.8	40.1	44.0	40.5	0.16	0.21	35	37
	35.3	35.4	42.0	39.5	0.06	0.31	29	31
	34.9	35.1	41.0	39.5	0.28	0.29	36	37
Mean	34.4	35.3	40.1	39.9	0.22	0.43	35	36

Appendix C2: Night time data

Table C6: Evaporators - A stream

Time	t_a (°C)		t_r (°C)		v (m/s)		rh(%)	
2000	E_{A1}	E_{A4}	E_{A1}	E_{A4}	E_{A1}	E_{A4}	E_{A1}	E_{A4}
	34.9	32.0	43.5	42.0	0.21	0.15	48	43
	35.1	33.4	44.0	43.0	0.36	0.44	42	42
	36.9	35.0	45.0	37.5	0.23	0.17	47	42
	35.5	34.0	44.5	43.5	0.03	0.27	44	46
Mean	35.6	33.6	44.3	41.5	0.21	0.26	45	43
2200	34.5	31.2	43.0	35.0	0.05	0.14	52	52
	36.5	36.0	45.0	44.5	0.09	0.21	46	47
	36.0	34.1	45.5	43.0	0.06	0.21	43	47
	34.0	33.3	43.0	42.0	0.14	0.13	51	51
Mean	35.3	33.7	44.1	41.1	0.09	0.17	48	49
2400	33.0	30.0	42.0	35.0	0.13	0.26	50	51
	36.5	34.2	45.5	38.5	0.17	0.22	36	39
	32.5	31.4	36.5	36.0	0.11	0.26	49	53
	32.8	31.5	35.0	35.5	0.26	0.64	51	51
Mean	33.7	31.8	39.8	36.3	0.17	0.35	47	49
0200	32.8	29.7	40.0	35.5	0.02	0.31	47	48
	33.3	30.8	42.5	35.5	0.13	0.21	41	46
	30.9	30.8	36.5	35.0	0.26	0.04	47	46
	30.5	29.8	36.0	35.0	0.09	0.34	39	43
Mean	31.9	30.1	38.8	35.3	0.13	0.23	44	46
0400	29.6	28.8	34.0	31.0	0.38	0.16	42	40
	30.0	29.2	35.5	37.0	0.09	0.21	40	40
	28.5	28.0	32.0	30.0	0.31	0.13	41	39
	28.6	29.0	31.5	32.5	0.42	0.18	41	39
Mean	29.2	28.8	33.3	32.6	0.30	0.17	41	40

Table C7: Evaporators - B stream

Time	t_a (°C)		t_r (°C)		v (m/s)		rh(%)	
2000	E_{B2}	E_{B3}	E_{B2}	E_{B3}	E_{B2}	E_{B3}	E_{B2}	E_{B3}
	32.0	33.8	35.0	36.5	0.85	0.93	48	45
	31.3	31.9	34.0	34.5	0.57	0.95	38	37
	34.7	35.0	37.5	39.0	0.81	0.79	49	45
	33.8	34.0	36.0	38.5	0.63	0.56	48	49
Mean	33.0	33.7	35.6	37.1	0.72	0.81	46	44
2200	31.7	32.1	34.0	35.0	0.60	0.05	52	52
	33.9	33.8	36.5	36.5	0.32	0.27	49	47
	33.0	33.5	36.5	36.0	0.42	0.39	51	50
	32.6	32.5	34.5	34.0	0.36	0.26	53	53
Mean	32.8	33.0	35.4	35.4	0.43	0.24	51	51
2400	30.0	30.7	33.5	33.5	0.64	0.64	46	46
	32.7	32.9	36.0	34.5	0.63	0.47	41	40
	31.8	32.0	34.5	36.5	0.43	0.39	46	45
	32.0	30.3	35.0	33.0	0.52	0.53	45	46
Mean	31.6	31.5	34.8	34.4	0.56	0.51	45	44
0200	29.3	28.9	32.5	31.5	0.58	0.26	45	49
	30.1	30.0	33.5	33.0	0.48	0.47	48	48
	29.8	31.2	32.0	35.5	0.59	0.31	46	48
	30.4	30.0	33.0	33.0	0.47	0.28	40	41
Mean	29.9	30.0	32.6	33.3	0.53	0.33	45	47
0400	28.0	28.1	31.5	31.0	0.78	0.39	35	38
	28.8	29.2	31.0	32.0	0.69	0.40	36	39
	28.5	29.8	32.0	32.5	0.69	0.41	36	39
	29.0	30.0	32.0	33.5	0.77	0.41	34	37
Mean	28.6	29.3	31.6	32.3	0.73	0.40	35	38

Table C8: Vacuum pans - Lower floor

Time	t_a (°C)		t_r (°C)		v (m/s)		rh(%)	
2000	P_2	P_5	P_2	P_5	P_2	P_5	P_2	P_5
	34.0	36.0	36.5	41.0	0.61	0.41	48	45
	36.3	38.1	41.0	42.0	0.36	0.21	47	39
	35.5	36.3	40.5	41.5	0.59	0.44	47	46
	34.4	36.9	36.0	41.0	0.43	0.39	47	47
Mean	35.1	36.8	38.5	41.4	0.50	0.36	47	44
2200	33.8	32.1	36.0	34.5	0.05	0.45	53	44
	38.1	38.1	42.5	42.0	0.42	0.51	49	49
	34.0	33.7	37.0	36.5	0.48	0.57	54	46
	33.5	34.0	36.5	36.5	0.26	0.43	54	50
Mean	34.9	34.5	38.0	37.4	0.30	0.49	53	47
2400	31.9	30.5	33.5	33.0	0.18	0.53	47	43
	35.2	34.6	40.5	36.0	0.39	0.37	39	40
	32.2	31.8	34.0	33.5	0.32	0.47	50	51
	31.3	32.0	33.5	34.0	0.13	0.22	46	47
Mean	32.7	32.2	35.4	31.1	0.26	0.40	46	45
0200	31.6	31.4	33.0	33.0	0.16	0.32	42	49
	30.0	29.8	33.5	32.0	0.39	0.47	47	48
	30.4	30.7	33.0	33.0	0.41	0.37	53	55
	29.7	30.3	32.5	33.5	0.26	0.32	42	42
Mean	30.4	30.6	33.0	32.9	0.31	0.37	46	49
0400	29.7	30.3	33.0	33.5	0.74	0.18	41	38
	29.3	28.4	32.5	31.5	0.57	0.43	42	39
	28.6	28.9	31.0	31.5	0.35	0.39	40	40
	28.1	28.8	31.5	31.5	0.68	0.29	39	36
Mean	28.9	29.1	32.0	32.0	0.59	0.32	41	38

Table C9: Vacuum pans - upper floor

Time	tdb (⁰C)			tr (⁰C)			v (m/s)			rh (%)		
2000	P_7	P_9	P_{11}	P_7	P_9	P_{11}	P_7	P_9	P_{11}	P_7	P_9	P_{11}
	33.8	34.9	35.5	40.5	41.0	41.0	1.04	0.70	0.60	52	55	49
	36.9	37.5	36.8	42.5	42.0	41.5	0.78	0.51	0.24	43	43	41
	36.4	37.0	37.2	40.0	41.5	41.0	0.97	0.76	0.63	53	56	51
	35.7	36.1	36.5	40.0	41.0	41.5	0.57	0.46	0.28	50	49	47
Mean	35.7	36.4	36.5	40.8	41.4	41.3	0.85	0.61	0.44	50	51	47
2200	32.0	31.2	32.6	38.0	37.0	38.0	0.53	0.13	0.15	43	41	40
	36.5	37.0	36.2	39.5	40.1	39.0	0.63	0.40	0.28	51	50	47
	35.0	36.0	36.5	38.0	39.5	39.5	0.51	0.27	0.18	53	49	48
	32.8	33.9	33.5	37.5	38.5	38.5	0.57	0.22	0.27	44	46	47
Mean	34.1	34.5	34.7	38.3	38.8	38.8	0.56	0.26	0.22	48	47	46
2400	30.4	30.5	31.0	36.0	36.0	36.0	0.24	0.22	0.34	45	46	44
	34.0	33.8	34.0	40.5	40.0	40.0	0.49	0.29	0.31	43	42	42
	32.7	34.2	32.3	39.0	40.5	39.5	0.41	0.29	0.36	53	52	53
	31.2	31.7	32.0	38.5	38.5	39.0	0.54	0.34	0.24	42	44	42
Mean	32.1	32.6	32.3	38.5	38.6	38.6	0.42	0.29	0.31	46	46	45
0200	29.9	28.3	29.7	32.5	31.0	32.0	0.54	0.35	0.30	44	41	43
	30.0	29.5	30.6	36.5	31.5	36.0	0.56	0.33	0.29	50	49	50
	31.0	32.3	30.1	37.5	39.0	36.0	0.64	0.37	0.29	43	43	43
	29.3	30.0	30.4	32.0	36.0	36.0	0.56	0.37	0.33	45	42	44
Mean	30.1	30.0	30.2	34.6	34.4	35.0	0.58	0.36	0.30	46	44	45
0400	28.5	28.0	29.1	31.0	31.5	32.0	1.00	0.58	0.28	47	47	41
	29.1	29.0	29.4	32.0	32.0	32.5	0.76	0.38	0.29	46	45	40
	30.2	30.8	29.6	36.5	36.0	30.0	0.73	0.53	0.27	47	47	42
	28.6	28.1	28.2	31.5	31.5	31.5	1.02	0.62	0.37	45	43	39
Mean	29.1	28.1	29.2	32.8	32.8	31.5	0.88	0.53	0.30	46	46	41

Table C10: Boiler house

Time	t_a (°C)		t_r (°C)		v (m/s)		rh(%)	
2000	1B	2B	1B	2B	1B	2B	1B	2B
	30.0	30.5	35.0	35.5	0.32	0.59	51	52
	30.5	30.5	35.5	35.5	0.31	0.59	47	46
	30.1	30.4	35.5	35.5	0.10	0.07	48	48
	29.0	29.0	33.5	33.5	0.46	0.39	51	52
Mean	29.9	30.1	34.5	35.0	0.30	0.41	49	50
2200	28.9	28.8	32.0	32.0	0.51	0.47	50	49
	29.7	29.7	33.5	33.5	0.46	0.39	51	51
	29.0	29.0	33.0	33.0	0.41	0.21	49	44
	27.2	27.0	32.0	32.0	0.29	0.21	53	50
Mean	28.7	28.6	32.6	32.6	0.42	0.32	51	49
2400	28.0	27.9	32.5	32.0	0.09	0.34	54	53
	28.0	28.0	33.5	33.5	0.25	0.22	48	45
	28.3	27.6	33.5	32.0	0.23	0.36	49	49
	26.9	26.5	31.0	31.5	0.37	0.26	53	56
Mean	27.8	27.5	32.6	32.3	0.24	0.30	51	51
0200	26.0	27.5	31.5	32.0	0.30	0.26	50	48
	26.5	27.1	31.5	31.5	0.41	0.33	41	43
	27.0	26.7	32.5	31.0	0.26	0.18	50	48
	25.0	25.3	27.5	27.5	0.30	0.32	59	57
Mean	26.1	26.7	30.8	30.5	0.32	0.27	50	49
0400	25.5	25.5	30.0	30.0	0.30	0.38	49	54
	26.0	26.3	31.5	31.5	0.49	0.37	47	49
	26.0	26.0	32.5	32.5	0.31	0.27	47	42
	25.0	25.0	27.0	27.5	0.41	0.21	43	38
Mean	25.5	25.7	30.3	30.4	0.38	0.31	47	46

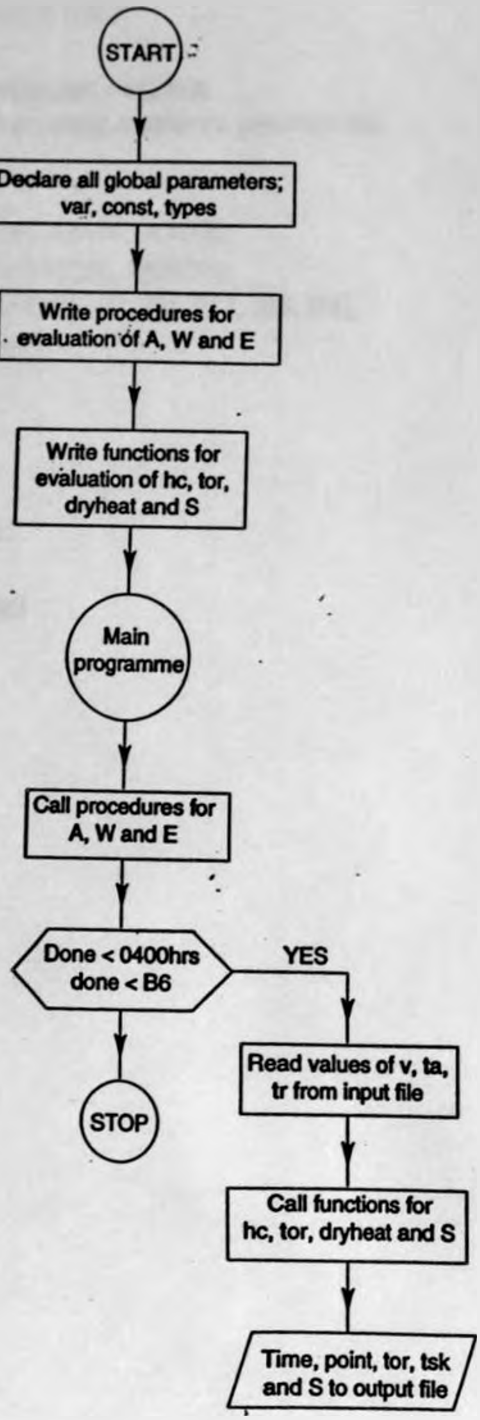
APPENDIX D

The Pascal Programme used in the evaluation of Thermal load imposed on the exposed workers.

Appendix D1: The flow Chart

Appendix D2: The Pascal Program

Appendix D1


START
Declare all global parameters; var, const, types
Write procedures for evaluation of A, W and E
Write functions for evaluation of hc, tor, dryheat and S
Main programme
Call procedures for A, W and E
Done < 0400hrs done < B6
YES
STOP
Read values of v, ta, tr from input file
Call functions for hc, tor, dryheat and S
Time, point, tor, tsk and S to output file

Appendix D2: THE PASCAL PROGRAM

PROGRAM CREATING INPUT FILE

```
program CompileInformation(input, output);
{This program creates a file for entering measured parameters}

type
 hours = (M0800, M1000, N1200, A1400, A1600,
          E2000, E2200, E2400, M0200, M0400);
 points = (Ea1, Ea4, Eb2, Eb3, P2, P5, P7, P9, P11, B5, B6);
 data = array[hours,points] of real;
 string1 = string[4];

var
 time : hours;
 period : array [hours] of string1;
 point : points;
 position : array [points] of string1 ;
 v, ta, tr, tcl : data;
 line1 : string[80];
 F : text;

begin
 period[M0800] := '0800';
 period[M1000] := '1000';
 period[N1200] := '1200';
 period[A1400] := '1400';
 period[A1600] := '1600';
 period[E2000] := '2000';
 period[E2200] := '2200';
 period[E2400] := '2400';
 period[M0200] := '0200';
 period[M0400] := '0400';
 position[Ea1] := 'Ea1';
 position[Ea4] := 'Ea4';
 position[Eb2] := 'Eb2';
 position[Eb3] := 'Eb3';
 position[P2]  := 'P2';
 position[P5]  := 'P5';
 position[P7]  := 'P7';
 position[P9]  := 'P9';
 position[P11] := 'P11';
 position[B5]  := 'B5';
 position[B6]  := 'B6';
```

```
 assign(F,'A:DATA.TXT');
 rewrite(F);
 writeln('enter v, ta, tr');
 writeln(F,'TIME  POINT    v     ta     tr');
 for time := M0800 to M0400 do
 for point := Ea1 to B6 do
  begin
   writeln(period[time],' ',position[point]);
   readln(v[time,point], ta[time,point], tr[time,point]);
   write(F, period[time],'   ', position[point],'   ', v[time,point]:4:2);
   writeln(F,'   ', ta[time,point]:4:1,'   ', tr[time,point]:4:1);
  end;{of input loop}
Close(F)
end.
```

PROGRAM FOR CALCULATING STORED HEAT

```
program StoredHeat(input, output);
{This program calculates stored heat using procedures and functions}

const
 M = 73.13;
 y = 0.67;
 hr = 5.2;

type
 hours = (M0800, M1000, N1200, A1400, A1600,
          E2000, E2200, E2400, M0200, M0400);
 points = (Ea1, Ea4, Eb2, Eb3, P2, P5, P7, P9, P11, B5, B6);
 string1 = string[4];

var
 S, W, E, R, C, A, dw, dt, wt, h, p, q, i, j : real;
 v, ta, tr, tsk, tor, hc, rc : real;
 nmv : string[3];
 time : hours;
 period : array[hours]of string1;
 point : points;
 position : array[points]of string1;
 Inp, Out : text;
 line1 : string[80];

procedure Announce;
begin
 writeln('This program calculates rate of heat being stored in the body');
end;{of procedure announce}

procedure CalculateA(var A, i, p, j, q : real);
const
 wt = 75;   {average weight of test person}
 h = 1.7;  {average height of test persons}
begin
 i := 0.425 * ln(wt);
 p := exp(i);
 j := 0.725 * ln(h);
 q := exp(j);
 A := 0.202 * p * q
end;{of procedure CalculateA}

procedure CalculateW(var W, A : real);
begin
```

```
 W := 49.05/A
end;{end of procedure CalculateW}

procedure CalculateE(var E, A : real);
const
 y = 0.67;
 dw = 250;  {change in weight in gm for an average person}
 dt = 1920; {change in time in min., i.e., 8 hr for 4 sampling days}
begin
 E := (60 * y)/A * (dw/dt)
end;{of procedure CalculateE}

function Calculatehc(v : real) : real;
begin
 Calculatehc := 8.3 * sqrt(v)
end;{of function Calculatehc}

function Calculatetor(hc, ta, tr : real) : real;
const
 hr = 5.2;
begin
 Calculatetor := ((hc * ta) + (hr * tr))/(hc + hr)
end;

function Calculatetsk(tor : real) : real;
begin
 Calculatetsk := 25.8 + (0.267 * tor)
end;

function CalculateDryHeat(hc, tsk, ta, tr : real) : real;
const
 hr = 5.2;  {radiant heat transfer coefficient}
begin
 C := hc * (tsk - ta);
 R := hr * (tsk - tr);
 CalculateDryHeat := C + R
end;{of function CalculateDryHeat}

function CalculateS(W, E, C, R : real) : real;
const
 M = 73.13;
begin
 CalculateS := M - W - E - (C + R)
end;{of function CalculateS}

{START OF MAIN PROGRAM}
```

```
begin
 Announce;
 CalculateA(A,p,q,i,j);
 CalculateW(W, A);
 CalculateE(E,A);
 assign(Inp,'A:DATA.TXT');
 reset(Inp);
 assign(Out,'A:RESULTS.TXT');
 rewrite(Out);
 writeln(Out,'TIME  POINT   tor    tsk     rc      S');
 readln(Inp,line1);
 for time := M0800 to M0400 do
 for point := Ea1 to B6 do
  begin
   readln(Inp,period[time], nmv, position[point] , v, ta, tr);
   hc  := Calculatehc(v);
   tor := Calculatetor(hc,ta,tr);
   tsk := Calculatetsk(tor);
   rc  := CalculateDryHeat(hc,tsk,ta,tr);
   S   := M - W - E - rc;
    write(Out,period[time], nmv, position[point],'  ', tor:4:1,'    ', tsk:4:1,'    ',rc:6:2,'
',S:6:2);
  end;{calculation loop}
 Close(Inp);
 Close(Out)
end.
```